PRECAMBRIAN ROCKS OF THE WHISTLERS MOUNTAIN TRAIL MAP - AREA, JASPER

DONALD BRYCE REMINGTON, B.Sc.

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THE UNIVERSITY OF ALBERTA

PRECAMBRIAN ROCKS OF THE WHISTLERS MOUNTAIN TRAIL MAP-AREA, JASPER

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF GEOLOGY

by

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Edmonton, Alberta

April, 1960

ABSTRACT

A small area of Precambrian rocks within the Main Ranges of the Canadian Rocky Mountains near Jasper, Alberta, was mapped. Rocks of the map-area belong to Walcott's Miette formation. In age, they are most likely Late Precambrian and correspond lithologically and perhaps stratigraphically to the Horsethief Creek formation of southeastern British Columbia and the Hector and Corral Creek formations of the Bow Valley. About 670 feet of these beds, consisting of nine alternating sandstone-conglomerate and phyllite units, were described and a petrographic and heavy mineral study made on selected samples.

Strata of the sandstone-conglomerate units are commonly graded and cross-bedded. The rocks of these units, which are mainly arkosic and subarkosic sandstones and conglomerates with some feldspathic graywackes, consist mostly of angular, poorly-sorted quartz and albite. Many pebbles are composed of chess-board twinned albite, which is thought to have formed from potash and plagioclase feldspar. Other pebbles are composed of vein quartz, recrystallized metamorphic quartz, stretched metamorphic quartz and rarely granitic rock. In addition, large shale inclusions are sometimes present. The remainder of the rock is sand-sized common (probably some plutonic) quartz, detrital muscovite, and sericite and chlorite matrix. Only the ultra-

stable heavy accessory minerals, zircon, tourmaline, apatite and rutile are present. Hyacinth and dark purple-brown zircons are well developed and commonly zoned.

The phyllite units are composed of laminated and very thinly bedded phyllite, consisting of sericite, chlorite and small amounts of sand-sized quartz.

The source-area for the sediments was probably close to the site of deposition, topographically high or rugged and composed of metamorphic and possibly some plutonic rocks. Deposition of the psammitic beds was probably in a deltaic environment where deposition was rapid. Frequent periods of loss in stream competency are suggested by the presence of graded beds. The pelitic units may have been deposited during periods in which there was a small relative rise in sea level; alternatively they could be inter-distributary deposits.

The rocks have been subjected to stress, probably during the Rocky Mountain orogeny of Lower Tertiary times. Structurally the area is underlain by an easterly plunging syncline and anticline. Slaty cleavage, which is essentially parallel to the axial planes of the folds, is well developed in the phyllite units. There has been slight metamorphism of the sediments which has fractured pebbles, formed new minerals (albite, sericite, chlorite) and destroyed others (potash feldspar and plagioclase). Mineralogically, the rocks correspond to the greenschist facies of regional metamorphism.

A number of veins cut the area and are resolved into 4 sets based on trend, size and composition. One set is composed essentially of chlorite, but the other three sets are mainly quartz with some albite and calcite. Since there is no twinning of carbonate in the veins, they were probably emplaced after the folding.

ACKNOWLEDGEMENTS

Acknowledgements are due to Dr. H.A.K. Charlesworth, under whose direction this study was undertaken, for his assistance in the field and in the preparation and writing of the thesis. To Dr. J. Lerbekmo, for his aid with the sedimentary petrology portion of the study, the writer is also indebted. The writer would like to express his appreciation to the staff of the Department of Geology for critically reading the manuscript. Financial assistance from a Graduate Fellowship, presented by the Consolidated Mining and Smelting Company of Canada Limited, is gratefully acknowledged.

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INTRODUCTION

The thesis subject is an investigation of the structure, stratigraphy and sedimentary petrology of some Precambrian rocks in the Rocky Mountains of Canada near Jasper, Alberta. The central Rockies, bounded on the west by the Rocky Mountain Trench and on the east by the Western Plains, consist of three structural divisions which are, from east to west, the Foothills, Eastern Ranges and Main Ranges. The Foothills, composed predominantly of Mesozoic beds, are separated from the Eastern Ranges, mainly Paleozoic strata, by the Nikanassin-Boule thrust. The Pyramid fault (Fig. 1) separates the Main Ranges, underlain by Precambrian and Lower Cambrian rocks, from the Eastern Ranges.

About one square mile of Precambrian beds, located 1½ miles southwest of the town of Jasper, was mapped in considerable detail. The area is bounded on the east by the Whistlers Mountain trail, on the south by the Miette River, and on the west and north by the Yellowhead Pass highway. The area provides excellent exposures of the Precambrian beds, especially of the more resistant strata which tend to form prominent ridges. An aerial photograph enlarged 3 times was used for a field base-map. The base for the geologic map (Fig. 2) is an enlargement of the photograph.

Precambrian beds of the Yellowhead Pass region were first described by McEvoy (1898, p. 31) as being composed

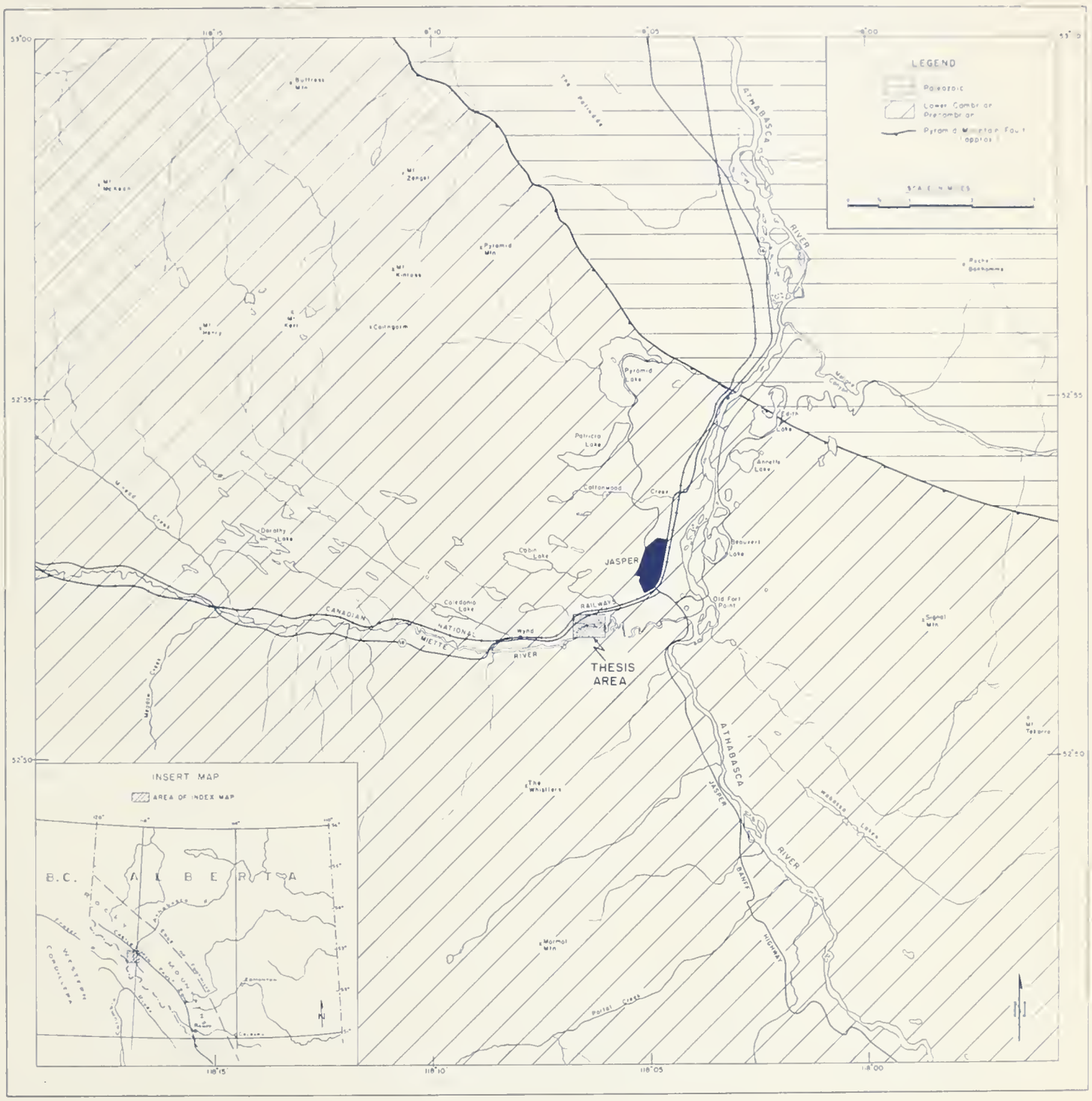

Fig. 1 Index map of the Jasper area showing the location of the Whistlers Mountain Trail map-area.

largely of altered conglomerates interbedded with micaceous, greenish gray slate. During his reconnaissance of the Mount Robson District of British Columbia, Walcott (1913, p. 340) described a succession of Precambrian beds which he called the Miette formation. These beds were described as being "massive-bedded gray sandstones with thick bands of gray and greenish siliceous shale". The rocks of the map-area belong to the Miette formation.

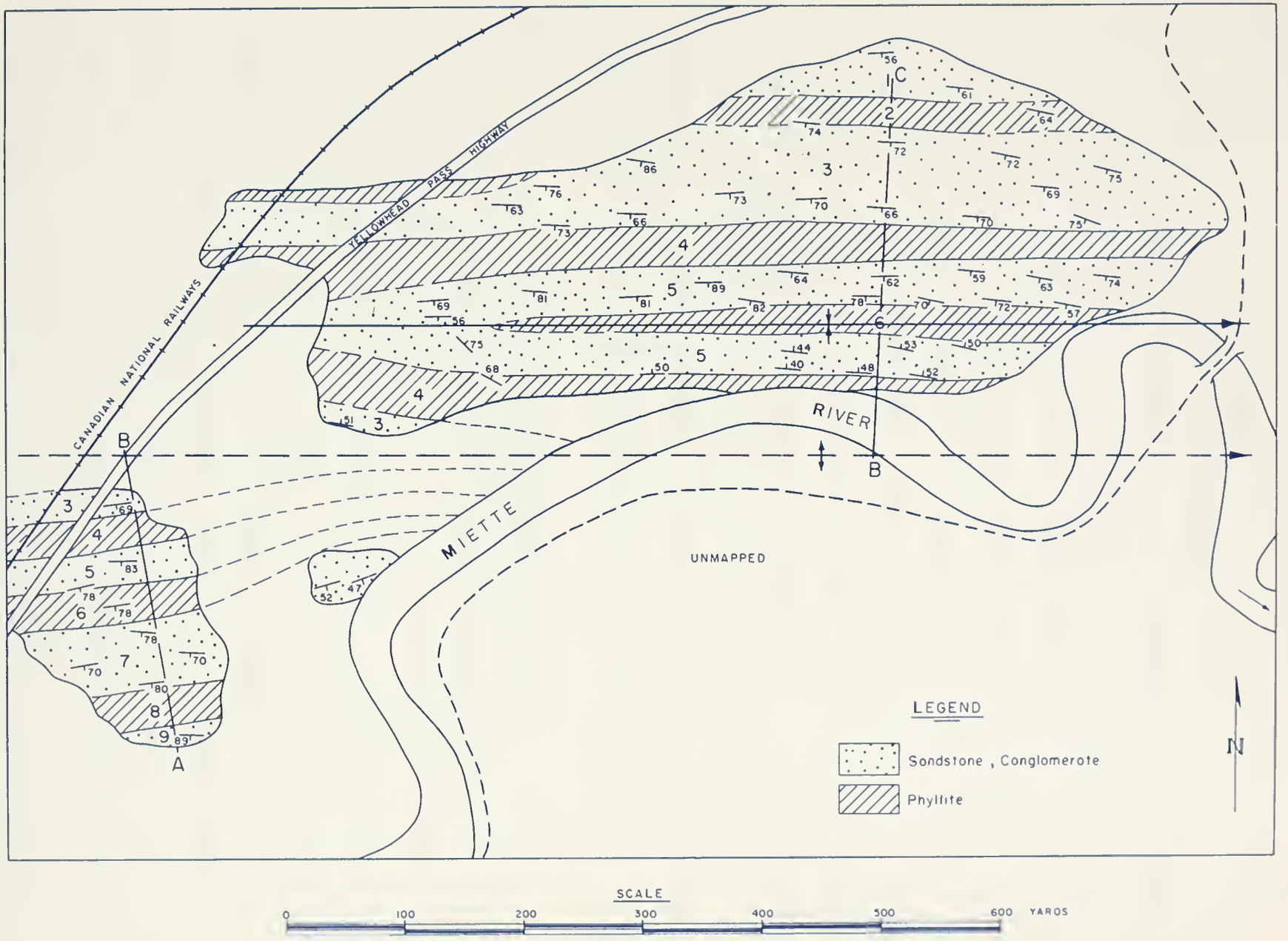

Fig. 2 Geologic map of the Whistlers Mountain Trail map-area. The structural section (Fig. 5) was drawn along the lines AB and BC.

STRATIGRAPHY AND PETROGRAPHY

Introduction

The Miette formation of the map-area is divisible into nine alternating units of sandstone-conglomerate and phyllite totalling 670 feet in thickness (Fig. 2; Plate 1, Figs. 1 and 3). Most of the section is well exposed, especially in the road-cuts on the Yellowhead Pass highway and on the front of a river-cut bluff. The contacts between the psammitic and pelitic units is often gradational, the phyllite units having several thin interbeds of sandstone or conglomerate and the sandstone-conglomerate units having thin phyllite interbeds near the contacts (Plate 2, Fig. 1). A detailed description of the section is given in the appendix.

Sandstone-Conglomerate Units

The thickness of the ridge-forming sandstone-conglomerate units ranges from 55 to 140 feet. The units are essentially made up of ungraded beds of pebble-conglomerate and sandstone, 3-10 feet thick, and slightly less numerous graded beds of pebble-conglomerate and sandstone usually about 5 feet thick. Both are occasionally as thin as 6 inches and as thick as 15 feet. At irregular intervals there are thin beds of very thinly bedded[1], medium-grained micaceous

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[1] See appendix, p. 34, for stratification terminology.

sandstone, which is finer grained and much thinner bedded than the other sandstones. Less frequently there are beds of laminated phyllite from 6 inches to 5 feet thick. Irregularly shaped shale inclusions are occasionally contained in the sandstone and conglomerate beds similar in appearance to the interbedded phyllitic layers except that they lack the cleavage-surface sheen (Plates 5, Fig. 3). Small granitic pebbles are also found.

Beds within the sandstone-conglomerate units are not persistent for more than a few tens of feet along strike. Tracing individual beds laterally disclosed strong lenticularity of the strata, frequent lateral facies changes (Fig. 2, unit 3), and occasional abrupt changes in lithology (Plate 2, Fig. 2).

Graded bedding is the most prominent sedimentary feature in the sandstone-conglomerate sequences (Plate 3, Figs. 1 and 2). The base of a graded bed is composed of fine-pebble conglomerate or pebbly sandstone which grades abruptly upward (Plate 3, Fig. 2) into a medium- or coarse-grained sandstone and sometimes into a very thinly bedded, finer grained micaceous sandstone. Quite frequently recurrent grading (Plate 3, Fig. 3) may lead to a single bed being as thick as 10 feet (see Kuenen, 1953, p. 1046).

Cross-stratification is a common sedimentary feature in the sandstone-conglomerate units (Plate 4, Figs. 1 and 2). It is of the simple and trough[1] type, each set being 1 to 3

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[1] Cross-stratification terminology is taken from McKee and Wier (1953, p. 387).

feet thick. Most sets are comprised of very thinly (1/2 - 2 inches) cross-bedded strata of either fine pebble-conglomerate or coarse-grained sandstone. The dip and azimuth of dip were measured on ten randomly chosen sets. Poles to the planes of bedding and cross-bedding were plotted on a stereographic net and the poles of the latter rotated until the cross-strata were in their original position of deposition (see Fisher, 1938, pp. 1261-71). Figure 3 is the plot of poles for the rotated cross-strata. Dips of the cross-beds range from 7° to 30° with a mean of 25°. Although the range of dip directions is large and the number of measurements few, the plots do suggest a westerly direction of dip.

Bedding surface features are rare. Interference ripple marks from the upper surface of a graded bed were identified in one instance (Plate 5, Fig. 1). Vague markings similar to these occur elsewhere but have a questionable origin. A structure of unknown origin occurs at the base of a conglomerate bed in unit 7 (Plate 5, Fig. 2). It has an asymmetrical fold shape, the folded portion being composed of sandstone with the steepest side toward the west. The structure has the appearance of a slump structure but it could also be a feature of load casting.

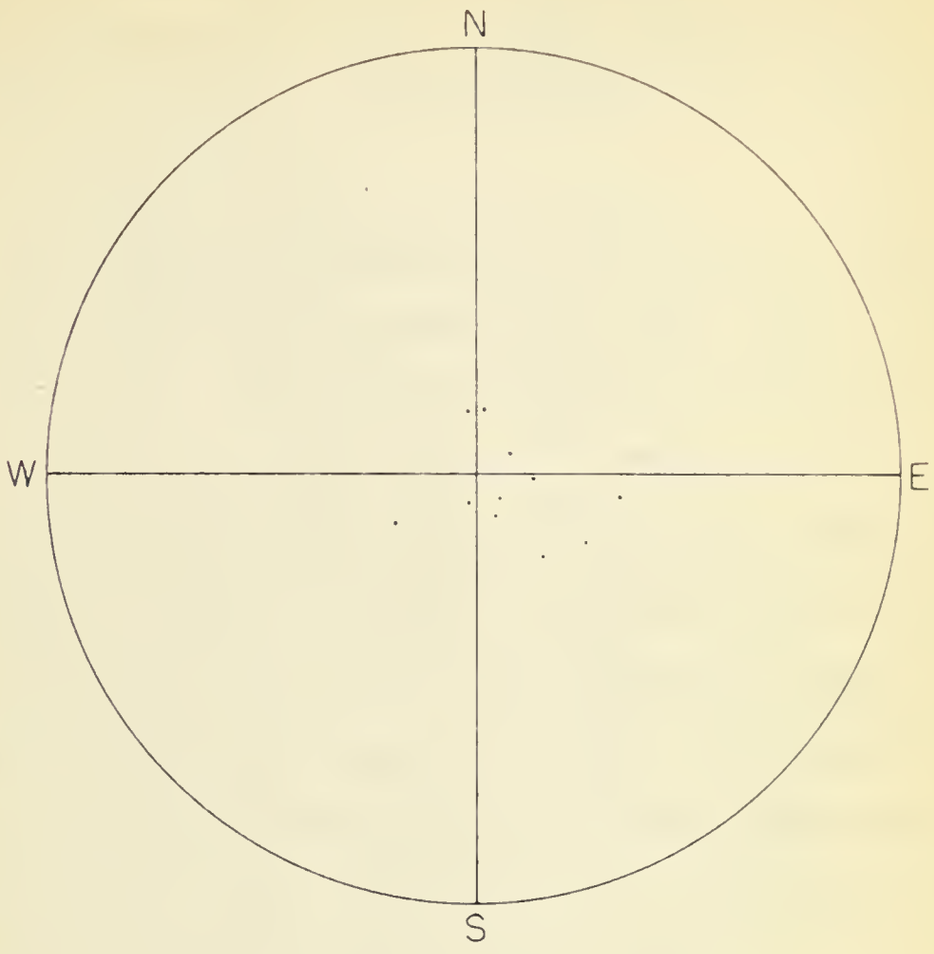

Fig. 3 Point diagram of 11 sets of cross-stratified beds. Poles to the cross-strata are plotted on the lower hemisphere of a stereographic net.

Most of the sandstones and conglomerates are light greenish gray (5 G 8/1)[1] to greenish gray (5 G 6/1) on the fresh surface, but occasionally may be light brownish gray (5 YR 6/1). Weathered surfaces are usually greenish gray to dark greenish gray (5 GY 4/1) and brownish gray (5 YR 4/1). Less commonly they are a medium- (N6) or an olive-gray (5 Y 4/1) color.

The sandstone-conglomerate units are all very poorly sorted and grain size may range from fine sand to fine pebbles in the same bed. Fine pebbly sandstone is the most common rock type (Plate 9, Fig. 1; Plate 7, Fig. 1), but coarse-grained sandstone (Plate 7, Fig. 3) and fine pebble-conglomerate (Plate 9, Figs. 2 and 3) are also common. Pebbles are usually elongate and in the fine pebble size (2-4 mm.), although some are as large as 15 mm. in length. Sand grains are generally subangular and pebbles are subrounded to subangular. Most pebbles have been fractured since deposition, probably the effect of shearing stress (see p. 12).

The sandstones and conglomerates have essentially the same mineralogy. The most common constituent is quartz, present as vein, metamorphic and common (including plutonic) types in order of abundance, and amounting to 60-70% of the

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[1] Numbers following a color indicate a specific color from the Rock Color Chart (The Rock Color Committee, 1953).

rock. Vein quartz and stretched metamorphic quartz account for about half of the pebble-sized fraction. It occurs predominantly as composite phenoclasts composed of individual quartz grains of variable size and shape with very crenulated boundaries. The grains are sometimes oriented with their c-axes nearly parallel. Extinction, whether in composite or single-grained phenoclasts, is moderately undulose. Many grains contain a few small vacuole inclusions, whereas primary mineral inclusions are absent. Recrystallized metamorphic quartz, also common, appears in the conglomerate and coarse sand phases. The phenoclasts are composite, made up of equi-sized grains much smaller than those of the vein quartz composites. Extinction is straight or slightly undulose. Grain boundaries are crenulated. Probable plutonic quartz comprises most of the sand-sized portion of the rocks. The grains have straight extinction with a few vacuoles and mineral inclusions. Composite grains of metamorphic and particularly vein quartz are frequently altered to vermicular chlorite (Plate 8, Fig. 2). The chlorite has anomalous "berlin-blue" interference colors. Petrographic studies suggest that the chlorite is not entirely secondary[1]. The green color of many sandstones and conglomerates is probably due to the chlorite.

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[1] When the chlorite crosses grains and matrix, this is taken as evidence for secondary chlorite, and when it appears only in the grain, this is taken as evidence for primary chlorite.

Plagioclase feldspar is the second most abundant mineral in the sandstones and conglomerates, averaging roughly 20% of the total volume. The feldspars were identified by staining[1], measurements of extinction angles on sections cut perpendicular to the X, Y and Z axes, and by an x-ray diffraction method. Failure of the feldspar to pick up the stain indicates that no potash feldspar is present. Optical[2] and x-ray[3] results suggest that the feldspar is nearly pure albite plagioclase.

Much of the pebble-sized albite differs distinctly from the sand-sized grains. The larger albite phenoclasts have chess-board albite twinning (see Starkey, 1950, pp. 140-2) (Plate 7, Figs. 5 and 6), similar to perthite in general appearance. The parallel twin-lamellae, unlike albite twin-lamellae, are not continuous along the crystal length. Sand-sized fragments, on the other hand, are twinned in the normal manner. Starkey (ibid, p. 144) has suggested that chess-board twinned albite may result from albitisation of perthite or microcline feldspar or from deformation of

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[1] The staining method employs sodium cobaltinitrite and is designed to stain potash feldspar yellow (Hayes and Klugman, 1959, pp. 227-32).

[2] Optical determinations of the plagioclase give Y $\wedge$ (010) = 17° and gamma less than 1.540, indicating a composition of An_0 (See Moorehouse, 1959, p. 57).

[3] $d_{(\bar{2}01)}$ spacing for pure albite - 4.03 A°.
$d_{(\bar{2}01)}$ spacing for potash feldspar - 4.23 A°.
$d_{(\bar{2}01)}$ spacing for specimen - 4.02 A°.
(Bowen and Tuttle, 1950, p. 493).

albitised potash feldspar crystals. The fact that only the pebble-sized albite shows this type of twinning strongly suggests that deformation does play a part in the formation of chess-board twinning (pebbles would be affected to a greater degree than sand-sized particles since the larger grains, being in contact with one another, would be subject to greater stress than the interstitial material). Some plagioclase feldspar was probably also present in the original sediment since it is unlikely that all the feldspar would be potassic.

Cleavage is often exceptionally well developed in the pebble-sized albite grains and is probably due to epigenesis since the cleavage planes are frequently separated by sericite or carbonate material. Alteration of albite to sericite (Plate 7, Fig. 4) and vermicular chlorite[1] (Plate 8, Fig. 2) is common, as is replacement by carbonate which usually spreads out from fractures and cleavage planes.

Mica (predominantly muscovite), as detrital grains in amounts up to 4%, is the most plentiful varietal mineral, usually between 1 and 3%. Most is in the fine and medium sand size. Many samples have up to 5% siderite[2], generally

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[1] Especially in rocks which have chloritized quartz.

[2] Some of the siderite could be ankerite.

as small rhombs partially and often completely altered to medium brown limonite (Plate 8, Fig. 1). The limonite is responsible for the brownish color of some rocks. Chlorite, in addition to its presence in quartz and feldspar, occurs in small amounts in the matrix.

The sandstones and conglomerates have considerable silt and clay-sized interstitial matrix. This is composed mostly of recrystallized clay material in the form of sericite, and particles of quartz and feldspar. It forms as much as 20% of some rocks, but is generally less.

The rocks were no doubt relatively impermeable with such a large quantity of interstitial material, explaining the conspicuous lack of cement. Calcite, present mainly in fractures of feldspar pebbles, sometimes is present as a cementing medium. Its occurrence as such is patchy and is never abundant.

Following Pettijohn's classification (1957, p. 291), most of the sandstones and conglomerates are arkoses and subarkoses, but many are feldspathic graywackes (Plate 7, Fig. 2) since they contain more than 15% matrix.

Heavy accessory minerals were studied from eleven samples of fine-grained sandstone. Sampling was restricted

to rocks with comparable grain size so that accurate comparisons could be made. The location in the section of each sample is shown in Figure 4.

Since the samples were particularly well indurated, they were broken first with a jaw crusher and then dissaggregated with a pulverizer. The material between 80 and 230 mesh was retained and treated with a 5% HCl solution. Tramp iron was removed with a bar magnet, whereupon the samples were weighed and poured into a separatory funnel containing tetrabromoethane (S.G.=2.9). After settling, the heavy minerals were drained off, washed with acetone, dried and weighed. Examination of the heavy mineral fraction showed a large amount of chlorite and some "light" minerals (mostly quartz). The chlorite was removed with the Frantz Isodynamic Separator at a setting of 0.30 amps. The percentage by weight of heavy minerals was not calculated since the samples contained a sizeable proportion of "light" minerals, most of which were clinging to opaque "heavies". Aroclor (n = 1.66) was used as the mounting medium since its index of refraction is reasonably close to that of most heavy minerals. All slides were examined with the petrographic microscope in transmitted light and statistical counts of nonopaque heavy minerals were made for each sample. Identification of opaque heavy minerals was not undertaken. In the order of abundance, the following nonopaque heavy minerals

were identified: zircon, tourmaline, apatite, and rutile. The tabulation of results is given in Figure 4.

Zircon appears as short prisms with pyramidal terminations. Essentially three varieties based on color are present: 1) pale, clear hyacinths[1], usually with tints of pinkish lavender (Plate 10, Fig. 6); 2) darker cloudy hyacinths (Plate 10, Figs. 7-9); and 3) dark purple-brown grains (malacons) (Plate 10, Fig. 10), which are often nearly opaque. Their abundance is shown graphically in Fig. 4b. According to Tomita (1954, p. 152), zircons break down and change color with time because of radiation bombardment from radioactive elements present in the zircon, so that hyacinth zircons represent those which have undergone considerable radiation. Tomita has proposed a Precambrian age for hyacinth zircons on the basis that this amount of time is required for enough radiation bombardment to change the color from colorless to hyacinth. Zoning is common in both the cloudy hyacinths and dark varieties (Fig. 4c; Plate 10, Figs. 7-9). Frequently, crystals with dark centers show a gradation toward paler peripheries (Plate 10, Fig. 8). Less often, small cracks radiate out from the centers of dark crystals. These have been attributed by Hutton (1950, p. 695) to expansion of the original zircon crystal due to radiation. Rounding is

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[1] The term hyacinth is used to denote zircons of pink, purple or reddish colors.

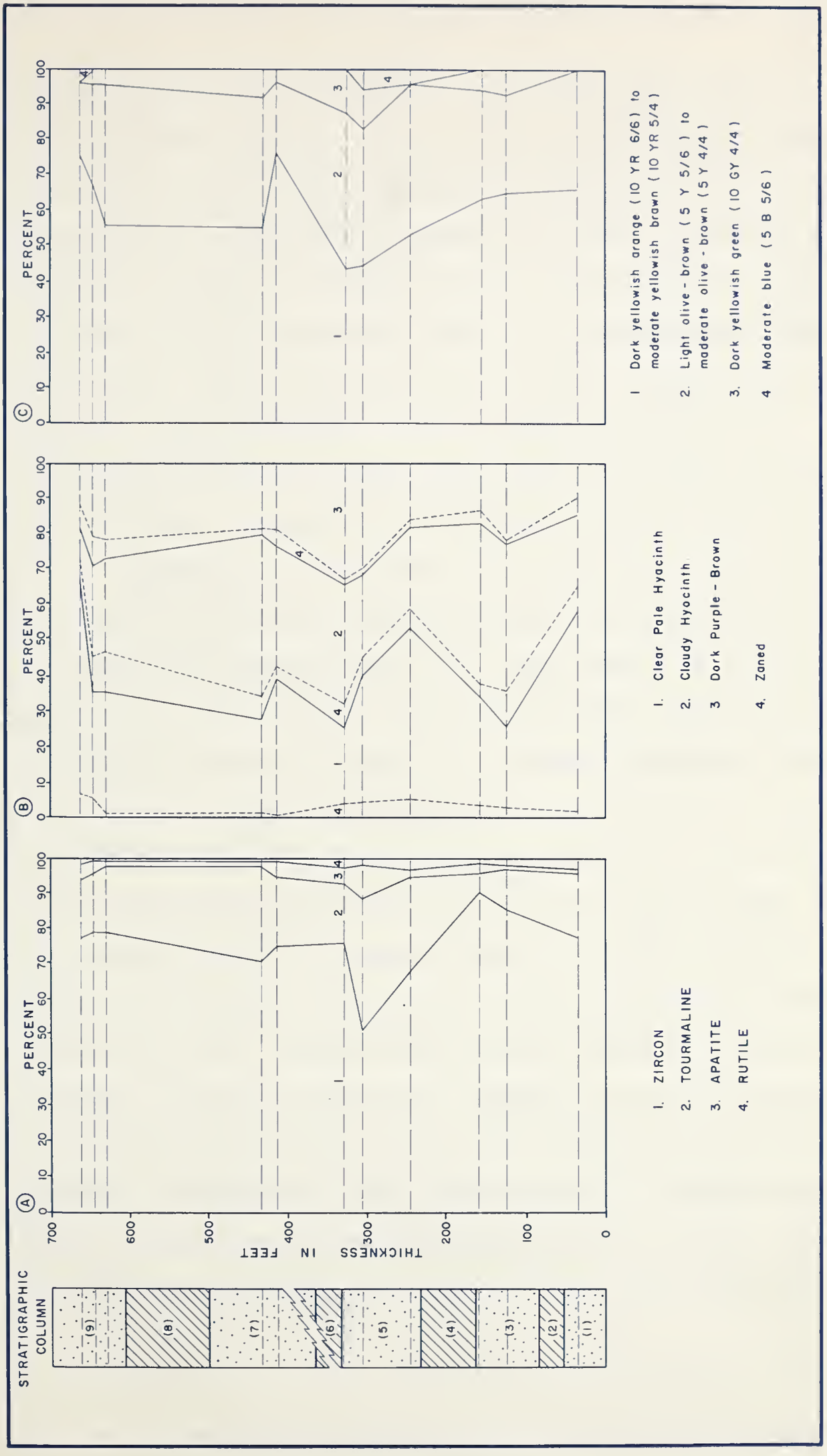

Fig. 4. Tabulation of the heavy mineral species and varieties and the sample locations in the section. (a) Heavy mineral species (b) Zircon varieties (c) Tourmaline varieties.

more pronounced in the case of the zircons than other heavy minerals present. About 75% are subrounded, 15% are rounded and well rounded and 10% are angular. There is no distinction in angularity between varieties. Euhedral and subhedral grains are abundant in all three types of zircon, although the pale hyacinths tend to be more anhedral than the others. Most crystals have at least one pyramidal termination. Small globular liquid or gas inclusions are occasionally present in the pale clear and cloudy hyacinths with sporadic occurrence of rod-shaped mineral inclusions.

Tourmaline is represented by four color varieties, the colors given being those produced by the ordinary ray. The frequency distribution of the four varieties is given in Fig. 4c. Most of the tourmaline is dark yellowish orange (10 YR 6/6) (Plate 10, Fig. 4) to moderate yellowish brown (10 YR 5/4). Light olive-brown (5 Y 5/6) (Plate 10, Fig. 3) to moderate olive-brown (5 Y 4/4) tourmaline is also abundant. A dark yellowish green (10 GY 4/4) type is less common, and the rarest variety is moderate blue (5 B 5/6), present in only three samples. All are generally subangular or angular, rounded and well rounded grains being completely absent. Elongate prismatic grains with irregular ends and irregular fractured fragments are common, the latter being the most typical. Frequently, grains contain rows of globular inclusions which are sometimes oriented parallel to the c-axis. In general, the grains are larger than those of other heavy minerals.

Apatite is mostly colorless (Plate 10, Fig. 1) although a few grains are light brown (Plate 10, Fig. 2). Angularity is pronounced and only rarely are grains rounded. Strongly etched apatites are common but these may be due to treatment of the samples with acid. Most grains are anhedral although subhedral types are present. Dusty and small globular inclusions are prominent in the brownish varieties, frequently in rows parallel to the c-axis.

Rutile is dark brown, reddish brown and amber. The dark brown variety is nearly opaque (Plate 10, Fig. 5). Longitudinal and oblique striations are common. Grains are elongate or prismatic with subangular and angular corners.

Although the proportions of each mineral and mineral species differs considerably from sample to sample, there is no trend to the distribution in this limited amount of section.

Phyllite Units

Separating and alternating with the sandstone-conglomerate units are bands of phyllite. They are somewhat thinner than the psammitic units, ranging from 30 to 105 feet thick. The beds consist of laminated and very thinly bedded phyllite with occasional thin beds of sandstone or conglomerate.

The phyllite beds and laminae are grayish olive (10 Y 4/2) or grayish olive-green (5 GY 3/2). Upon weathering, they are rusty brown or rusty maroon colored or occasionally

grayish olive-green and olive-gray (5 Y 4/1). The phyllites consist of sericite and fine-grained chlorite with variable amounts (usually 10-15%) of fine sand- and silt-sized quartz. Varietal minerals include coarser grains of chlorite and muscovite. Magnetite and zircon are present as accessory minerals. A few beds in the road-cuts tend to be slightly dolomitic, but on the whole the phyllite units are not calcareous or dolomitic[1]. The phyllites have sericite and muscovite aligned parallel to the cleavage, giving the rocks a poorly developed sheen.

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[1] The presence of dolomitic beds only in the road-cuts may be because the rocks are fresh, whereas other exposures are deeply weathered.

PROVENANCE AND DEPOSITIONAL ENVIRONMENT

The mineralogy and texture of the particles making up a clastic sediment give an indication as to the composition and character of the source-rocks. It is evident that the original sediments of the area have undergone alteration since burial, leading to the crystallization of new minerals (albite, sericite and chlorite) and the breaking down of others (potash and plagioclase feldspar). However, enough evidence remains to suggest the provenance.

The abundance of coarse feldspar and some plutonic (?) quartz indicates that the source-area may have been partly plutonic. Since much of the albite is probably altered alkali feldspar, the source likely contained coarse-grained acidic igneous rock. Heavy accessory minerals of the psammitic units are of limited significance as far as provenance is concerned: only the ultrastable minerals are present, implying that intrastratal solutions have removed any unstable accessory minerals. The angularity of the heavy minerals, with the exception of the zircon, indicates that they probably have a primary source. Rounding of the zircons is pronounced and could mean that they were derived from reworked sediments. However, Poldervaart (1956, p. 351) notes that rounded zircon has been observed in granites and proposes that corrosion in the magma chamber has resulted in the rounding of many zircons.

If this be the case, the zircon along with the apatite may have come from an acid igneous source (see Pettijohn, ibid, p. 513). The tourmaline could either be from a low rank metamorphic terrane injected by pegmatites, or from granitic rocks (see Krynine, 1946, p. 67-9). The large size of the fragments suggests a pegmatitic source. Rutile, which occurs in small amounts, may be from basic igneous rocks (see Pettijohn, ibid, p. 513).

The presence of abundant metamorphic quartz and vein quartz indicates that the source-area was probably largely underlain by metamorphic rocks. The evidence for plutonic source-rocks may be open to some argument. The absence of sedimentary rock fragments suggests that the source-area was lacking in sedimentary rocks.

The size and abundance of coarse material is a measure of the rapidity of erosion and thus a measure of the source-area relief (Pettijohn, ibid, p. 511). Since the feldspar and metamorphic quartz fragments are both large and numerous, it is evident that erosion was rapid and relief high, with little time for chemical weathering of the feldspar. The feldspar grains in the psammitic rocks are generally much larger than the plutonic quartz grains even though they are more susceptible to mechanical breakdown by abrasion. Since feldspar in granitic rocks is usually coarser grained than quartz, the abrasion history of the feldspar appears to have been short, suggesting that the source-area was not far

from the site of deposition. General lack of well rounded pebbles also suggests this.

Thus, the evidence indicates that the source-area, consisting mostly of metamorphic rocks with a minor plutonic component, was topographically high or rugged and relatively close to the site of deposition. Cross-bedding suggests that this source lay to the east of the area of deposition and probably consisted of the metamorphic and igneous rocks of the Churchill Province of the Canadian Shield (see Burwash, 1958, p. 217).

The character of a clastic sedimentary rock, in addition to being determined by the provenance and transportation, is also a product of the depositional environment. The environment of deposition is reflected in the physical and chemical nature of the rocks and is deciphered from their texture, structure and mineralogical composition.

The writer believes the most logical setting for the deposition of the sandstone-conglomerate units is deltaic, at the foot of a mountainous area where the associated streams were depositing a large amount of detritus in a subsiding area. The character of the psammitic rocks indicates that there was very little sorting or abrasion during transportation and that sedimentation was rapid. The graded bedding, which is common in some sandstones and conglomerates, was

probably formed by rivers as products of waning currents[1] (Kuenen, ibid, p. 1045; Pettijohn, ibid, p. 171). Many ancient deposits of the Mississippi River show excellent competency grading (Kuenen, ibid, p. 1044). Irregular strata, lensing beds and lateral changes in grain size are common in the sandstone-conglomerate units and are characteristic of deltaic deposits (Shepard, 1956, p. 2521). Rich (1951, pp.1-20) has described a near-shore environment which he calls the unda ("wave") environment. He suggests that rocks which were deposited in the deltaic parts of this environment will have a great range in grain size (silt to gravel) cross-bedding, nonpersistent beds, ripple marks and lack of sorting if subsidence was rapid. All these features are typical of the psammitic units.

The pelitic units may have been deposited during periods in which there was a small relative rise in sea level. The thin bedding and fairly persistent thickness of the pelitic units laterally suggests deeper water sedimentation. There is also the possibility that they are deposits of inter-distributary regions of the delta and are not deep water deposits. This is suggested by the presence of thin beds of similar pelitic material in the sandstone-conglomerate units.

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[1] Graded bedding may also be formed by turbidity currents (see Pettijohn, ibid, pp.171-2). The graded beds occurring in these sandstone-conglomerate units are not likely to have been caused by turbidity currents since the graded beds do not have a gradual change in grain size from bottom to top. Moreover, some beds of the psammitic units have large scale cross-stratification and are lenticular, which features are not typical of turbidity flow deposits (Kuenen, ibid, pp. 1045-6).

AGE AND CORRELATION

The psammitic and pelitic beds of the map-area belong to the Miette formation of Walcott (ibid, p. 340), which is said to be unconformably overlain by Lower Cambrian strata. The rocks are most likely of Late Precambrian age. Probable coeval strata, belonging to the Windermere group, outcrop elsewhere in the Canadian Rocky Mountains and Western Cordillera of British Columbia. Correlation of the Miette formation with these beds can only be attempted on the basis of similarities in lithology and stratigraphic position. The Horsethief Creek formation of southeastern British Columbia (Walker, 1926, pp. 14-5; Rice, 1941, pp. 17-8), the Hector and Corral Creek formations of the Bow Valley (Walcott, 1910, p. 428) and the Miette formation of Jasper are all quite similar lithologically. Beds of phyllite, quartzite, and pebbly and feldspathic pebbly quartzite, and quartz pebble-conglomerate are common to all three formations. Reesor (1957, p. 160) believes that, because of their lithologic similarities and mutual proximity to the Cambrian, the three formations may be correlated.

STRUCTURE AND METAMORPHISM

Introduction

The rocks of the map-area have been subjected to considerable shearing stress and have, as a result, undergone structural deformation and metamorphism. Although no evidence was found to suggest the time of deformation, it most likely occurred during the Rocky Mountain orogeny, thought to have taken place in Lower Tertiary times (Russell, 1954, p. 68).

Structure

The structure of the Precambrian strata is simple, consisting of a syncline and anticline which strike east-west and plunge gently to the east (Figs. 2 and 5; Plate 1, Fig. 2). The axial trace of the syncline is 400 feet north of the anticline. Both folds are somewhat asymmetrical, the north limb of the syncline and the south limb of the anticline dipping 70°-80° south and the common limb dipping 50° north. Outcrops of the strata forming the anticline and the syncline close to the east and west respectively, indicating an easterly plunge. The intersection of bedding with cleavage, observed in unit 6 of the bluff region, suggests that the plunge of the anticline is about 10° east.

Slaty cleavage is developed in the incompetent phyllite units. A number of measurements on the attitude of cleavage planes at various localities suggest that it is approximately parallel to the axial planes of the folds. On the north limb of the syncline, slaty cleavage in unit 4 strikes parallel to the bedding but dips 85° south - 13° steeper than the bedding. On the south limb of the anticline, cleavage in unit 4 cuts across the bedding parallel to the anticlinal axis and dips south about 15° steeper than the bedding. Also on the south flank of the anticline, but farther from the axis, the cleavage trends parallel to the bedding but is vertical.

Metamorphism

It is evident from petrographic studies on the psammitic and pelitic beds that the rocks have undergone metamorphism. The fabric of the coarse rocks has not been appreciably altered, so that metamorphism was probably slight. Recrystallization and alignment of mica in the phyllite beds, fractured pebbles in the conglomerates and the well indurated nature of many of the rocks are the most obvious results of metamorphism. The greenish color of most rocks, coarse and fine, is caused by the presence of the low grade metamorphic mineral, chlorite. The pelitic beds are especially rich in chlorite. Sericite has formed at the expense of the fine-grained matrix in all

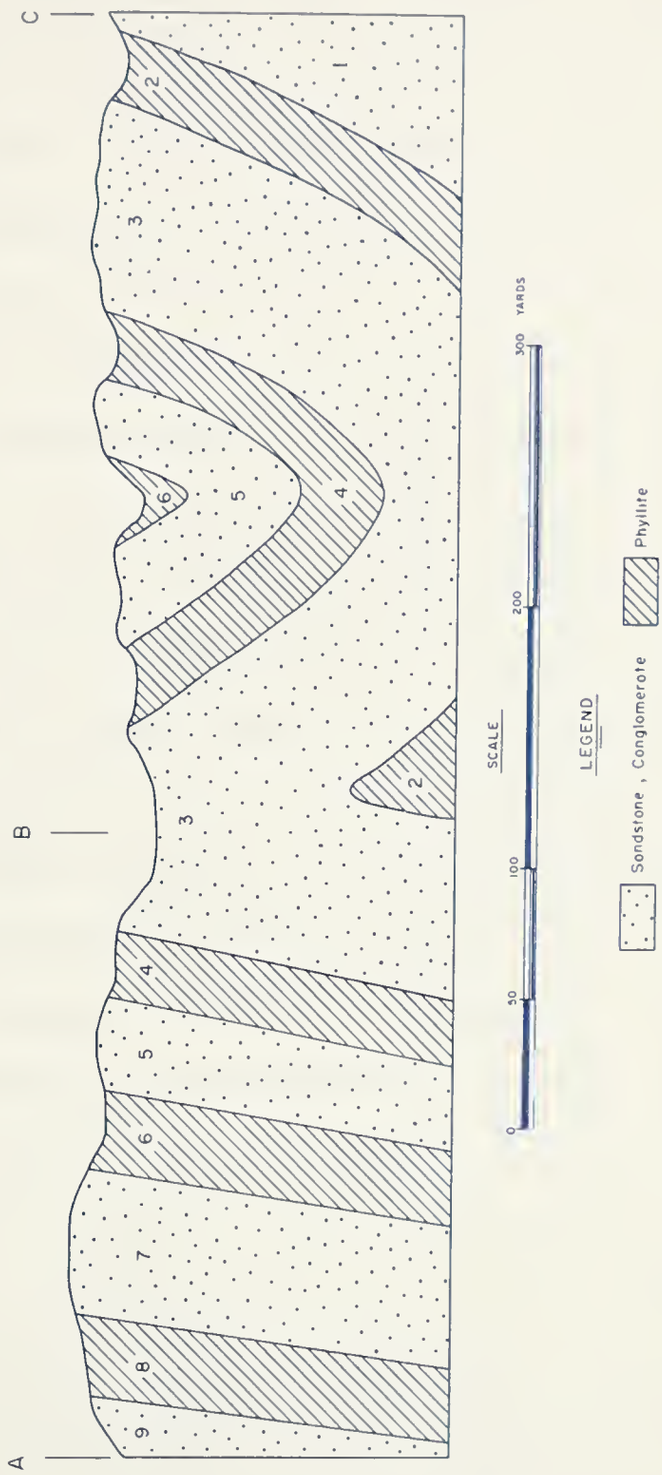

Fig. 5 Structural cross section of the map-area along AB and BC (see Fig. 2).

rocks and as an alteration product of feldspar in the coarse beds. Albite seems to have formed from pre-existing alkali feldspar (microcline and/or perthite) and from plagioclase. Siderite (possibly with some ankerite), often present as euhedral rhombs, is no doubt a secondary mineral, probably of metamorphic origin. During albitisation, escaping K^{+} ions from the potash feldspar were probably adsorbed by the argillaceous material to form sericite, while migrating Ca^{++} ions from the plagioclase formed calcite (and perhaps ankerite) in the psammitic beds. The ions required to form albite, chlorite and the carbonates could have come from pre-existing minerals as a result of reorganization of material, or they may have been introduced from outside the system.

Considering the large number of variables involved in determining the composition of a metamorphic rock, the mineralogy of the rocks studied is remarkably similar to the subfacies quartz-albite-muscovite-chlorite of the greenschist facies (Fyfe et al., 1958, pp. 166-73; pp. 217-22). The physical conditions as established by geologic observation and experimental data for the greenschist facies, are thought to be temperatures above 300° C. and load pressures of around 3,000 bars (depth of burial from 10 to 30 km.) (Fyfe et al., ibid, p. 218). However, similar metamorphic conditions were probably reached at much lower temperatures and lesser depths of burial during the Rocky Mountain orogeny, when the rocks were subjected to considerable shearing stress.

VEINING

Veins are a prominent feature of some sandstone-conglomerate units, especially in the north flank of the syncline. Only very short, narrow veins are present in the bluff area. The veins do not extend into the less competent phyllite units.

In unit 5 on the north and south limbs of the syncline and in unit 3 on the north flank, are the best developed veins, divisible into four sets according to size, trend and composition. The widest and commonest set (set 1 in Fig. 6) trends north-northwest (average N 17° W) and dips 65°-80° northeast, being particularly well-exposed on the dip slope of unit 3 (Plate 6). Their average width is 1/2-1 inch. In unit 5 on the north limb of the syncline, about 16 of these veins occur in a 12-foot wide zone striking N 48° W. Quartz, sometimes as well developed crystals in the wider veins, is the dominant mineral present, although cream-colored calcite rhombs also occur (especially in the wider veins). The relationship between the calcite and the quartz was not determined. A second set (set 2 in Fig. 6), also best observable on the dip slope of unit 3, trends N 5° E and dips gently (15°) west. These veins are slightly narrower than the first set and are characterized by the presence of green vermicular chlorite (up to 75%) (Plate 8, Figs. 3 and 4). Other minerals

present include large, well developed Carlsbad- and albite-twinned plagioclase (probably albite) with small amounts of quartz and calcite. One particularly wide (6-8 inches) vein, which has a small amount of galena, occurs in a brecciated zone, and contains rock-fragments embedded in the vein. A third set of veins (set 3 in Fig. 6), in unit 5 on the south limb of the syncline, strikes northwest (N 27° W) and dips 60°-80° southwest. These veins are 1/2 to 1 inch wide and are similar to set 1 in composition, consisting mainly of quartz. A fourth set of veins, occurring in the north limb of the syncline, are irregular, narrow (about 1/4 inch), and shorter than other veins. These are composed of quartz, some carbonate and rarely some albite. On the whole, all veins are compositionally similar to the host rocks. The material of the veins was probably derived, at no great depth, from rocks of similar composition to those in which they occur, as the result of the activity of hydrothermal solutions.

Displacement along the veins was observed at one locality suggesting that set 4 was emplaced first, followed by set 2 and finally set 1 (Plate 6, Fig. 3). The age relationships of the third set are not known. The poles to the first three sets of veins have been plotted on the lower hemisphere of a stereographic net (Fig. 6). Only those veins whose attitudes could be accurately measured have been plotted. The age of emplacement of the veins, as suggested by the lack of twinning in the vein carbonates, is probably post deformation.

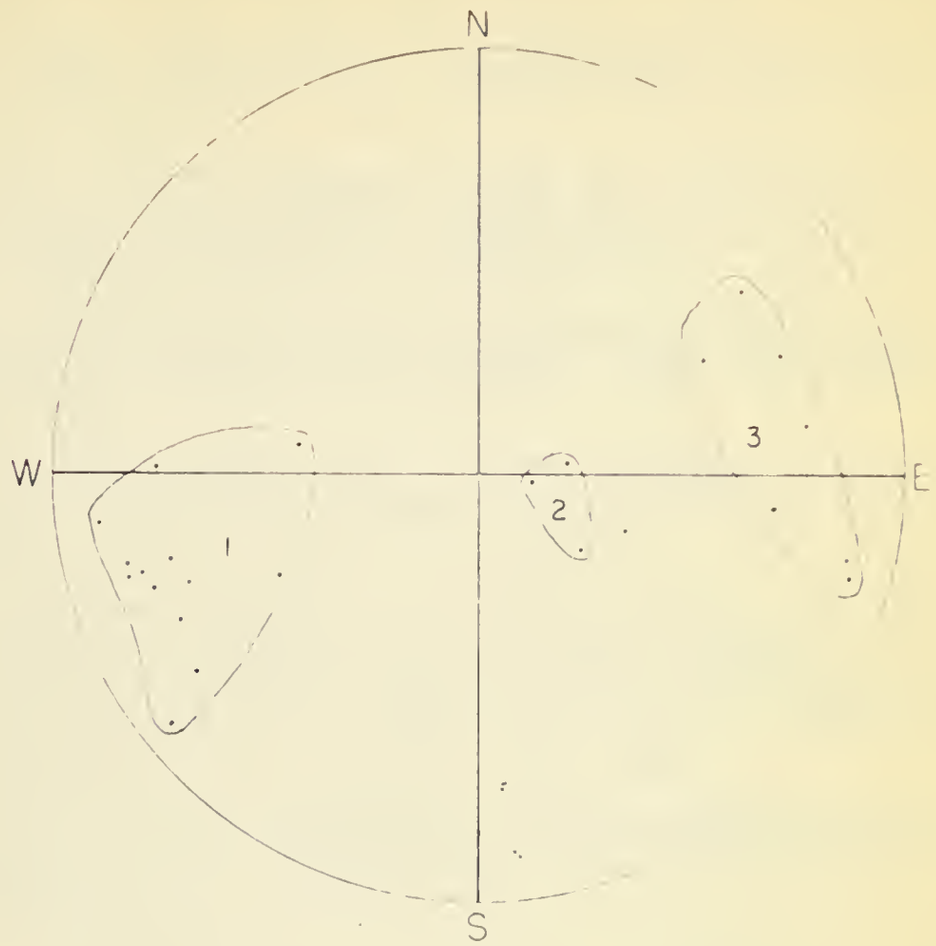

Fig. 6 Point diagram of 3 vein sets. Poles to the veins are plotted on the lower hemisphere of a stereographic net.

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APPENDIX

DESCRIPTION OF SECTION

Descriptions are from field notes
and binocular microscope examination.

Interval (feet)

TOP

Unit 9

666-670 SANDSTONE - Coarse-grained; dirty light brownish gray; thin bedded[1]; subangular[2], poorly sorted[3], predominantly quartz, small amount of chlorite, greenish grains, numerous limonitic grains, cement lacking[4]; lower contact sharp.

665-666 PHYLLITE - Dark greenish gray; bedding obscured by cleavage and fracturing.

664-665 *SANDSTONE - Similar to sandstone above.

653-664 PHYLLITE - Moderate greenish gray; laminated near base, very thin bedded at top; frequent thin beds of laminated sandstone.

638-653 *SANDSTONE - Fine-grained; greenish gray; thick bedded; abundant chlorite, mostly quartz; slight sheen on cleavage planes; upper 2' is very thin bedded and greener; lower contact sharp.

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[1] Very thick bedded: 4' plus; thick bedded: 2'-4'; medium bedded: 1'-2'; thin bedded: 2"-1'; very thin bedded: 1/2"-2"; laminated: 1/8"-1/2".

[2] Sand grains are subangular and pebbles are usually subrounded in all rocks.

[3] All rocks are poorly sorted especially the pebbly or conglomeratic rocks.

[4] Cement is lacking in all rocks in the section.

* Asterisk indicates the description is from binocular microscope examination.

629-638 *SANDSTONE & PHYLLITE - Irregularly interbedded. Sandstone - fine-grained; greenish gray; medium bedded; very numerous green grains, mostly quartz, small grains of limonitic siderite. Phyllite - similar to above pelitic beds. Lower contact sharp.

615-629 *CONGLOMERATE & *SANDSTONE - Irregularly interbedded, some phyllite intercalations. Conglomerate - fine pebbles (½ of rock), some up to 15 mm. long; dirty gray; common green pebbles, mostly quartz. Sandstone - medium-grained; light brownish gray. Lower contact sharp.

610-615 *SANDSTONE - Grades up from underlying conglomerate; medium-grained; light brownish gray; very thick bedded; quartz mostly, some feldspar (?), a few altered siderite grains.

605-610 *CONGLOMERATE - Fine pebbles (¼ of rock) although some up to 10 mm. long; light olive-gray; very thick bedded; predominantly quartz, some limonitic grains; sharp lower contact.

597-605 PHYLLITE - Dark greenish gray; occasional beds of micaceous very fine grained sandstone.

596-597 SANDSTONE - Grades up from underlying sandstone; fine-grained; greenish; thin bedded.

594-596 SANDSTONE - Coarse-grained; dirty dark green; medium bedded; occasional dark green pebbles; sharp lower contact.

590-594 SANDSTONE & PHYLLITE - Interbedded; similar to beds below.

587-590 *SANDSTONE - Coarse-grained; interbedded with thinly laminated phyllite; light brownish gray; thick bedded; cross-bedded in upper portion; lower contact sharp.

Unit 8

497-587 PHYLLITE - Dark grayish green, weathers rusty-brown; very thin bedded to laminated; strongly cleaved; lower contact sharp.

Unit 7

493-497 SANDSTONE & PHYLLITE - Interbedded; similar to beds below.

491-493 PHYLLITE - Moderate gray-green, weathers rusty-brown; laminated; strongly cleaved; lower contact sharp.

486.5-491 *SANDSTONE - Coarse-grained; greenish gray; thick bedded; mostly quartz and feldspar, small amount of chlorite, frequent limonitic grains.

486-486.5 SANDSTONE - Fine-grained; greenish; very thin bedded; micaceous, fairly well developed sheen; sharp lower contact.

481-486 CONGLOMERATE - Fine pebbles (1/2 of rock); brownish green; thick bedded; numerous green pebbles, mostly quartz, common altered siderite grains; grades up to a very coarse-grained sandstone; sharp lower contact.

477-481 PHYLLITE - Dark dirty green, weathers slightly rusty; laminated; sharp lower contact.

473-477 SANDSTONE - Very coarse-grained; light greenish gray; thick bedded; mostly quartz, rare green grains, brown limonitic grains; grades up to a more greenish micaceous sandstone; lower contact sharp.

464-473 CONGLOMERATE - Fine pebbles (1/2 of rock); brownish gray; lower half is medium bedded; upper half becomes thick bedded; frequent large dark green pebbles, mostly quartz and some feldspar; upper part grades into slightly finer conglomerate; sharp lower contact.

462-464 SANDSTONE - Fine-grained; moderate green, clean looking; medium bedded, becomes very thin bedded near top; frequent limonitic grains; upper surface is undulatory; lower contact is sharp.

461-462 SANDSTONE - Grades up from underlying sandstone; medium-grained; dark greenish gray; thin bedded; top part is fine-grained sandstone, dark green, micaceous.

459-461 *SANDSTONE - Very coarse-grained; light greenish gray; medium bedded; mostly quartz, elongate green grains common; gradational lower contact.

456-459 SANDSTONE - Fine-grained; greenish, weathers rusty; micaceous, lower contact sharp.

450-456 PHYLLITE - Dark olive-green; laminated; sharp lower contact.

441-450 CONGLOMERATE & *SANDSTONE - Irregularly interbedded. Sandstone - medium-grained; greenish gray; mostly quartz, some chlorite. Conglomerate - similar to conglomerate beds below.

437-441 CONGLOMERATE - Fine pebbles; similar to conglomerates below; brownish; very thick bedded; sharp lower contact.

432-437 *SANDSTONE - Fine-grained; greenish gray; thick bedded; very numerous green grains, chlorite and muscovite common; lower contact gradational (?).

431-432 SANDSTONE - Fine-grained; moderate green; very thin bedded; micaceous, imparting a slight sheen; sharp lower contact.

430-431 SANDSTONE - Grades up from underlying conglomerate; numerous green grains.

421-430 *CONGLOMERATE - Fine pebbles (1/3 of rock); light olive-gray; thick bedded; quartz, abundant feldspar, numerous green pebbles, a few limonitic grains; lower contact sharp and undulatory, separated from underlying sandstone by a very thin bedded greenish sandstone.

419-421 SANDSTONE - Grades up from conglomerate below; similar to underlying sandstones; very little matrix.

416-419 CONGLOMERATE - Fine pebbles; thick bedded; frequent green pebbles, some very large pelitic pebbles; shows slight recurrent grading; lower contact is sharp.

410-416 SANDSTONE - Grades up from underlying conglomerate; coarse-grained; light brownish gray; thick bedded; quartz and feldspar predominantly, numerous limonitic grains.

399-410 CONGLOMERATE - Similar to conglomerate bed above; sharp lower contact, separated by a thin bed of phyllite.

397-399 (variable) CONGLOMERATE - Mostly fine pebbles; greenish; medium bedded; mica common, numerous fragments of gray and brown phyllite; lower contact sharp.

392-397 SANDSTONE & PHYLLITE - Interbedded. Sandstone - fine-grained; greenish; medium bedded; micaceous. Phyllite - dirty green, weathers rusty-brown; laminated; occasional thin interbeds of sandstone. Lower contact is sharp.

387-392 PHYLLITE - Dirty green, weathers rusty; laminated; poorly developed sheen; one thin bed of sandstone similar to underlying bed; sharp lower contact.

386-387 SANDSTONE - Medium-grained; dark greenish, dirty appearing; thin bedded; micaceous imparting a slight sheen, limonitic specks numerous; lower contact gradational.

382-386 PHYLLITE - Similar to underlying interbeds; weathers rusty-maroon; fractured; sharp lower contact.

378-382 *CONGLOMERATE & PHYLLITE - Interbedded. Conglomerate - fine pebbles (1/4 of rock); greenish gray, weathers rusty-maroon; badly weathered. Phyllite - gray, weathers rusty; fractures obscure bedding; sharp lower contact.

372-378 *SANDSTONE - Very coarse-grained, slightly pebbly; greenish gray, weathers light gray; very thick bedded; quartzose, some feldspar and green grains; upper part is graded, medium-grained sandstone; sharp lower contact.

367-372 *CONGLOMERATE - Fine pebbles (about 1/3 of rock); medium gray, weathers light gray; very thick bedded; composed of quartz mostly (occasionally some smoky quartz), some feldspar, common green pebbles; upper surface is undulating; lower contact sharp.

Unit 6

334-367 PHYLLITE - Covered

Unit 5

330-334 SANDSTONE - Pebbly; brownish gray; medium bedded; mostly quartz and feldspar, some green pebbles, some limonitic grains, small amount of matrix; sharp lower contact.

329-330 *SANDSTONE - Fine-grained; greenish gray, weathers slightly darker; very thin bedded; abundant chlorite and muscovite giving the rock a sheen on cleavage surfaces; gradational lower contact.

326-329 SANDSTONE - Very coarse-grained; light brownish green, weathers brownish gray; medium bedded; mostly quartz, some greenish grains, small amount of chlorite and muscovite; gradational lower contact.

319-326 *SANDSTONE - Medium-grained; greenish gray, weathers dark greenish gray; medium bedded; composed of quartz, some feldspar, frequent green grains, abundant muscovite and chlorite, common altered siderite grains; gradational lower contact.

315-319 CONGLOMERATE - Fine pebbles (about 2/3 of rock); greenish gray; medium bedded; mostly quartz, small percent of feldspar, muscovite and chlorite common, some altered siderite grains, numerous green pebbles; lower contact sharp.

314-315 SANDSTONE - Similar to beds below; lower contact sharp.

305-314 *CONGLOMERATE - Similar to conglomerate bed above; excellent cross-stratification; lower contact sharp.

300-305 *SANDSTONE - Medium-grained; light brownish gray, weathers grayish brown; thin bedded; mostly quartz, small amount of feldspar, some mica, numerous altered siderite grains; good cross-bedding; sharp lower contact.

291-300 *CONGLOMERATE - Fine pebbles (1/2 of rock); greenish gray, weathers light gray; medium bedded; amethyst quartz common, small amounts of mica and chlorite, predominantly quartz, some feldspar; lower contact sharp.

289-291 SANDSTONE - Very coarse-grained; light greenish gray; thin bedded; numerous limonitic siderite grains; cross-bedded; lower contact gradational.

286-289 CONGLOMERATE - Similar to conglomerate below; lower contact sharp.

285-286 SANDSTONE - Similar to sandstone bed below; gradational contact with underlying conglomerate.

282-285 *CONGLOMERATE - Fine pebbles (1/3 of rock) of quartz mostly; light brownish gray; thick bedded; some feldspar, mica and chlorite common, small amount of altered siderite; lower contact gradational (?).

281-282 SANDSTONE - Medium-grained; light brownish gray, weathers darker brownish gray; thin bedded; less matrix than usual, some mica, limonitic siderite common; cross-bedded; lower contact gradational.

276-281 CONGLOMERATE - Similar to conglomerate bed below; lower contact gradational.

275-276 SANDSTONE - Medium-grained; brownish gray; thin bedded; mostly sand-sized material - small amount of matrix; lower contact gradational (?).

272-275 CONGLOMERATE - Fine pebbles (1/4 of rock); brownish gray; thick bedded; numerous green grains, micaceous, numerous limonitic siderite grains, mostly quartz, some feldspar; lower contact sharp.

266-272 SANDSTONE - Grades up from underlying pebbly sandstone; medium-grained; greenish brown; thin bedded; common green grains, micaceous; somewhat cross-bedded.

259-266 *SANDSTONE - Pebbly, coarse-grained; light brownish gray; medium bedded; elongate quartz and feldspar pebbles, rare green grains, micaceous, common limonitic siderite grains; lower contact gradational.

254-259 SANDSTONE - Medium-grained; brownish gray; medium bedded; abundant mica, altered siderite common; upper surface is irregular; lower contact sharp.

246-254 CONGLOMERATE - Similar to conglomerate bed below; numerous limonitic grains; lower contact sharp.

240-246 *SANDSTONE - Coarse-grained; light brownish gray, weathers medium brownish gray; medium bedded; quartz, some feldspar, micaceous, numerous grains of limonitic siderite; lower contact gradational.

230-240 *CONGLOMERATE - Fine pebbles; very light gray, weathers medium gray with a brownish tinge; thick bedded; occasional green grains, small amount of mica, some limonitic siderite grains; sharp lower contact.

Unit 4

170-230 PHYLLITE - Poorly exposed; laminated and thinly bedded; dark grayish green, weathers dark rusty-brown; lower contact gradational.

Unit 3

169-170 SANDSTONE - Fine-grained; dark greenish gray; laminated; very micaceous giving the rock a sheen; gradational lower contact.

167-169 CONGLOMERATE - Fine pebbles (1/4 of rock); light greenish gray, weathers dark brownish; medium bedded; composed of quartz and feldspar; lower contact sharp.

165-167 *SANDSTONE - Fine-grained; dirty dark green; very thin bedded; micaceous, intercalated with thin beds of phyllite; lower contact gradational (?).

163-165 CONGLOMERATE - Fine pebbles; light greenish gray, weathers dark maroonish brown; medium bedded, varies; sharp lower contact.

161-163 PHYLLITE - Similar to other phyllite beds; rusty weathering.

159-161 SANDSTONE - Grades up from conglomerate below; medium-grained; light greenish gray, weathers dark green-brown; thin bedded; micaceous; upper surface is very irregular and marked by knobs and depressions.

152-159 CONGLOMERATE - Fine pebbles of quartz and feldspar; light greenish gray; above average feldspar content; lower contact sharp.

147-152 SANDSTONE - Medium-grained; greenish gray, weathers maroonish or rusty gray-green; medium bedded, upper part is thin bedded and micaceous giving the rock a sheen; lower contact sharp.

143-147 CONGLOMERATE - Fine pebbles; similar to conglomerate bed below.

142-143 SANDSTONE - Medium-grained; light greenish gray; thin bedded; micaceous giving the rock a phyllitic appearance; lower contact sharp.

141-142 PHYLLITE - Laminated; rusty weathering.

139-141 *CONGLOMERATE - Fine pebbles; light greenish gray; medium bedded; pebbles are quartz and feldspar, elongate, occasional green pebbles; lower contact gradational.

135-139 SANDSTONE - Coarse-grained, slightly pebbly; weathers dark gray; sharp lower contact.

130-135 SANDSTONE - Very coarse-grained; light gray; thick bedded; mostly clear quartz grains, some feldspar; sharp lower contact.

126.5-130 SANDSTONE - Medium-grained; light gray; medium bedded; similar to beds below; lower contact sharp.

126-126.5 *SANDSTONE - Fine-grained; greenish gray; very thin bedded; very micaceous giving the rock a sheen on the cleavage surfaces; lower contact sharp.

116-126 *SANDSTONE - Coarse-grained, some beds are pebbly; greenish gray; thick bedded; predominantly quartz (some is smoky quartz) and feldspar, micaceous, common limonitic siderite grains; lower contact gradational.

111-116 *SANDSTONE - Fine-grained; light greenish gray; thin bedded; quartz and feldspar, large grains of muscovite, some green grains, small amount of limonitic siderite; lower contact sharp.

105-111 *CONGLOMERATE - Fine pebbles (about 1/2 of rock) of quartz and feldspar, rare green pebbles, muscovite abundant, chlorite less common; lower contact sharp.

102-105 SANDSTONE - Medium-grained; greenish gray; thick bedded; lower contact sharp.

101-102 CONGLOMERATE - Similar to conglomerate bed below; gradational lower contact.

100-101 SANDSTONE - Grades up from underlying conglomerate; medium-grained; similar to sandstone bed below.

99-100 *CONGLOMERATE - Fine pebbles of quartz and feldspar; greenish gray; thin bedded; pebbles are elongate and some up to 12 mm. long, small amounts of chlorite and muscovite; lower contact gradational.

85-99 *SANDSTONE - Interbedded with thin beds of phyllite; mostly coarse-grained; light gray (some greenish gray); medium bedded; mostly quartz and feldspar, occasional green grains, somewhat micaceous.

Unit 2

55-85 (variable) PHYLLITE - Covered.

Unit 1

45-55 *SANDSTONE - Coarse-grained; light gray with brownish flecks of limonitic siderite; medium bedded, very thin bedded and greenish near the top; consists mostly of quartz, some feldspar, rare green grains; lower contact is sharp.

35-45 SANDSTONE - Medium-grained; greenish gray; medium bedded; frequent beds of very thin bedded greenish sandstone; micaceous; some suggestion of ripple marks on upper surface.

33-35 *SANDSTONE - Fine-grained; greenish gray; thin bedded; composed largely of quartz and feldspar, green grains common, small amount of chlorite, brown limonitic grains in small amounts.

30-33 SANDSTONE - Pebbly, similar to pebbly sandstone below; medium bedded; grades up to a finer grained sandstone.

28-30 SANDSTONE - Graded, similar to sandstone below except the upper portion is more micaceous resulting in laminations.

24-28 *SANDSTONE - Pebbly; greenish gray; thick bedded; dominantly quartz and feldspar, chlorite abundant, a few green pebbles; grades up to a coarse-grained sandstone.

18-24 *SANDSTONE - Grades up from underlying conglomerate; coarse-grained; greenish gray; very thick bedded; mostly quartz and feldspar, some green grains, small amount of chlorite.

15-18 *CONGLOMERATE - Fine pebbles of quartz and feldspar; light gray with frequent brown grains of limonitic siderite; pebbles are elongate; lower contact covered.

0-15 CONGLOMERATE - Poorly exposed

BOTTOM

ILLUSTRATIONS

Description of Plates

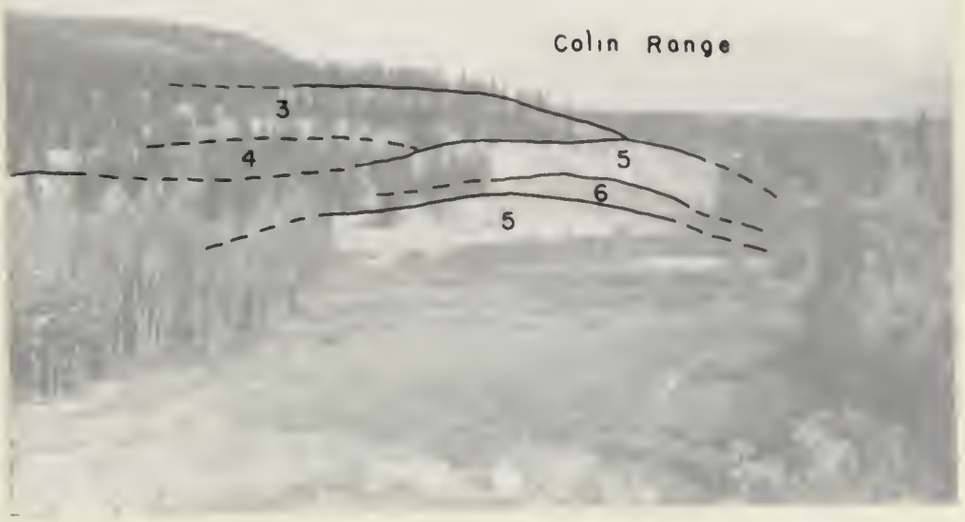
Plate 1

Field Photographs

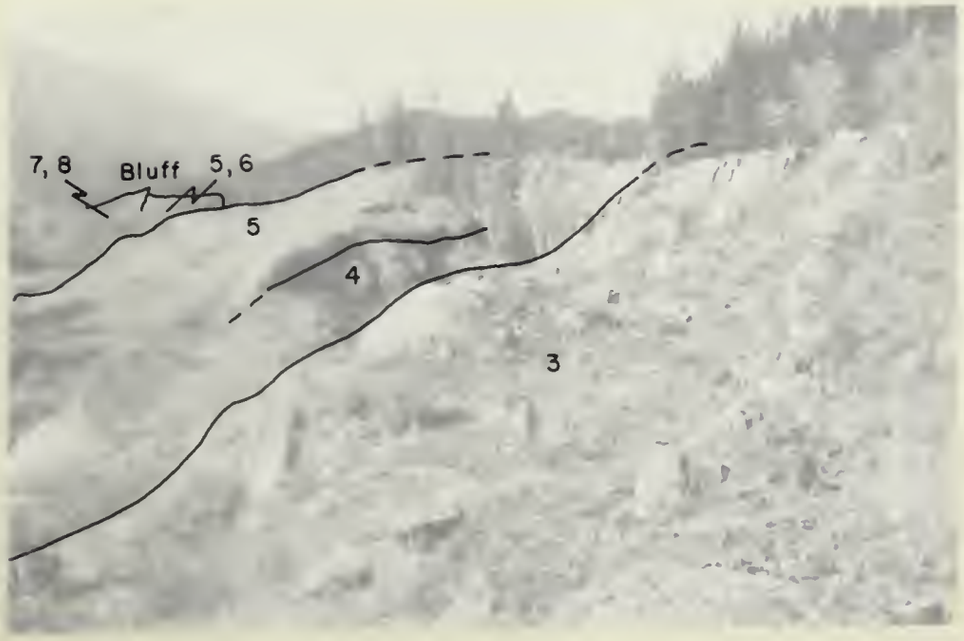
Figure 1 Outcrop pattern of units 3-6 as viewed from the south side of the Miette River looking northeast. The Paleozoic Colin Range northeast of the Pyramid Thrust, is in the background. Trees have been cleared for the new Yellowhead Pass highway.

Figure 2 The axis of the syncline as seen from the Whistlers Mountain Trail footbridge, looking west and parallel to the strike of the structures.

Figure 3 Outcrops of units 3, 4 and 5 in the foreground; in the background units 5-8 are seen exposed on the bluff. View is from unit 3 looking southeast.


Colin Range
3
4
5
6
5

5
5
6


7, 8
Bluff
5, 6
5
4
3

Colin Range
3
4
5
6
5

5
6
5

7, 8
Bluff
5, 6
5
4
3

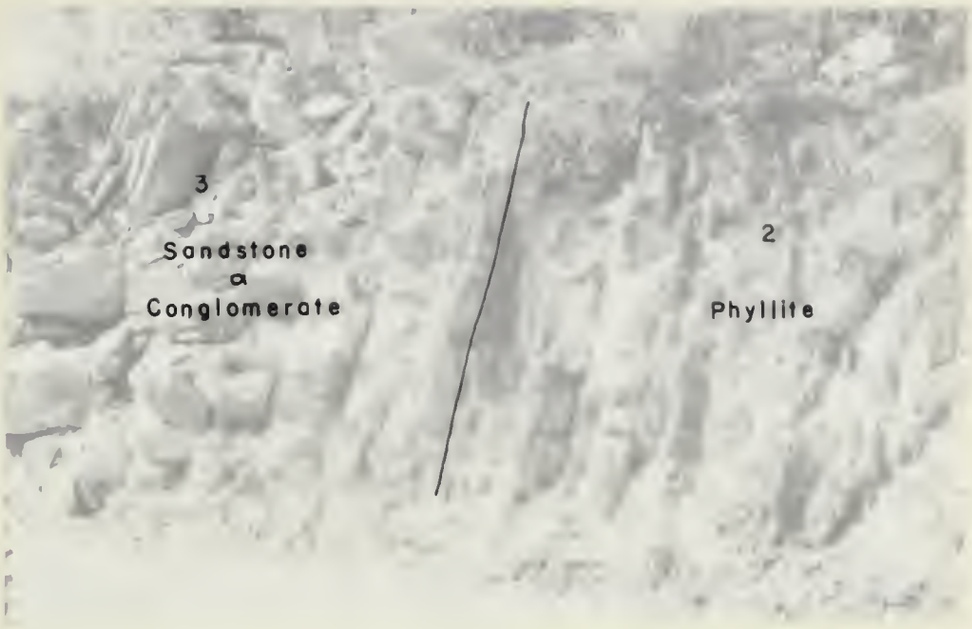
Description of Plates

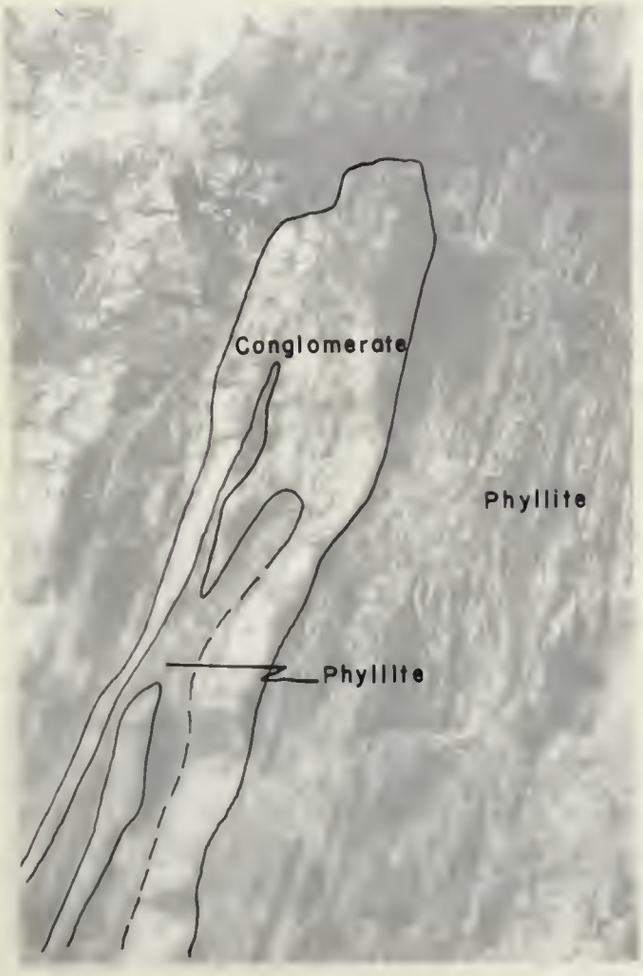
Plate 2

Field Photographs

Figure 1 Contact of phyllite (unit 2) and sandstone-conglomerate (unit 3) seen in a road-cut on the Yellowhead Pass highway. The exposure is about six feet high.

Figure 2 Lithologic change along strike of some conglomerate beds (3 feet thick) in unit 8. In the upper right hand corner, the conglomerate gives way abruptly to phyllite. The conglomerate bed is intercalated with phyllite.


3
Sandstone
a
Conglomerate
2
Phyllite


Conglomerate
Phyllite
Phyllite

3
Sandstone
&
Conglomerate
2
Phyllite

Conglomerate
Phyllite
Phyllite

Description of Plates

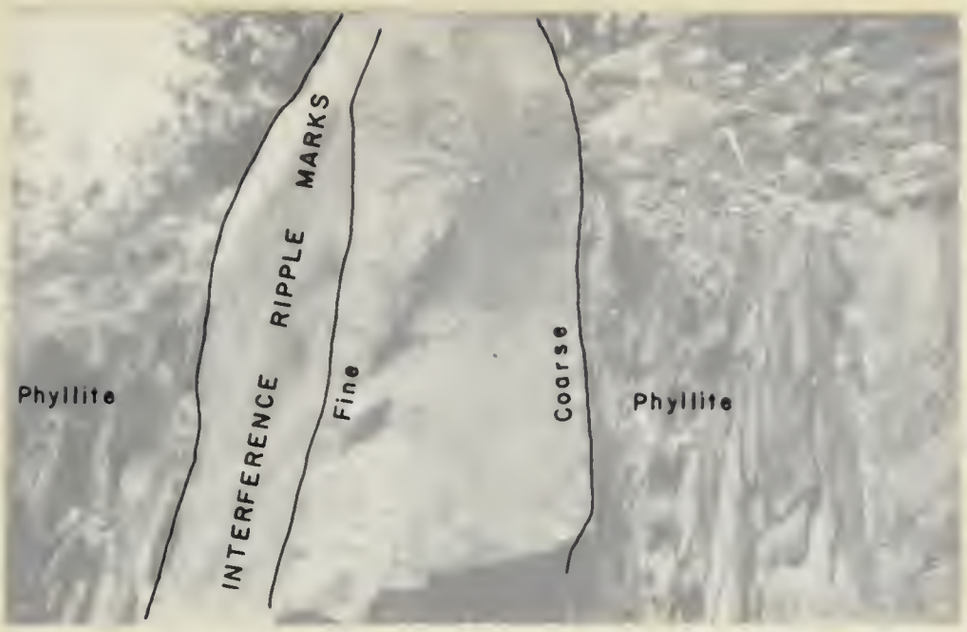
Plate 3

Field Photographs

Figure 1 Graded bedding seen in a road-cut along the Yellowhead Pass highway, looking west along the strike of unit 4. The base is a fine pebble-conglomerate, grading up (to the left) to a sandstone. Interference ripple marks can be seen on the upper bedding surface (see plate 5, fig. 1).

Figure 2 Graded bed in unit 5 on the south limb of the syncline. At the base is a fine pebble-conglomerate which grades up very rapidly to a medium-grained sandstone.

Figure 3 Recurrent grading in an 8 foot bed in unit 5 of the bluff sequence. Lense-shaped sandstone bed below hammer handle.


Phyllite
INTERFERENCE RIPPLE MARKS
Fine
Coarse
Phyllite

Sandstone
Conglomerate

Sandstone
Sandstone
Conglomerate
Sandstone

RIPPLE MARKS
INTERFERENCE
fine
coarse
phyllite
phyllite

sandstone
conglomerate

sandstone
conglomerate
sandstone
sandstone

Description of Plates

Plate 4

Field Photographs

Figure 1 Cross-stratification in a fine pebble-conglomerate of unit 5 looking west. Upper bed is graded.

Figure 2 Cross-stratification in sandstone several feet east of Fig. 1, looking west.

CURRENT
BEDDING

Fine
Graded Bed
Coarse
CURRENT
BEDDING
Conglomerate

Fine
Graded Bed
Coarse
CURRENT
BEDDING
Conglomerate

CURRENT
BEDDING

Description of Plates

Plate 5

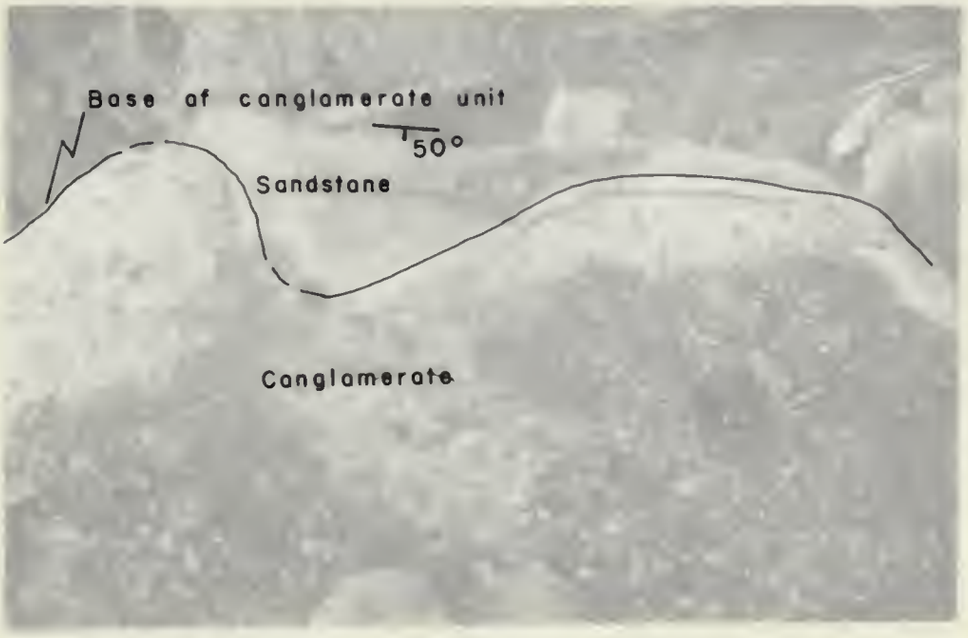
Field Photographs

Figure 1 Interference ripple marks on the surface of a graded bed (see plate 3, fig. 1).

Figure 2 Slump structure or load cast at the base of a conglomerate unit. The hammer is lying on the underlying sandstone. The strike of the beds is parallel to the hammer handle and the dip is 50° as indicated by the overlay.

Figure 3 Irregular shaped shale inclusion in a sandstone bed of unit 3.

INTERFERENCE
RIPPLE MARKS
Phyllite


Base of conglomerate unit
50°
Sandstone
Conglomerate

SHALE
INCLUSION

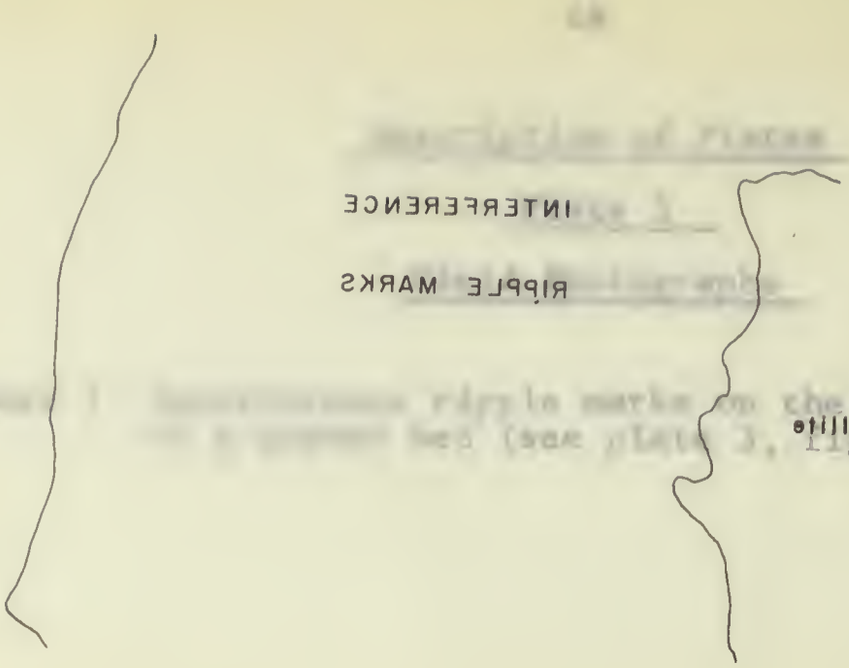


Figure 1. Interference ripple marks on the surface of a graywacke bed (see plate 3, fig. 1).

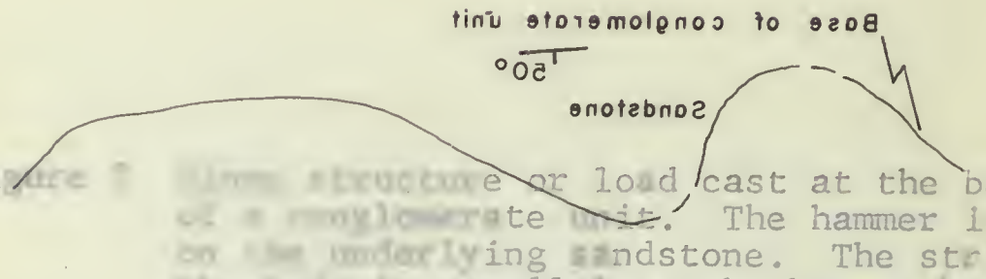


Figure 2. Flow structure or load cast at the base of a conglomerate unit. The hammer is lying on the underlying sandstone. The strike of the beds is parallel to the hammer handle and the dip is 50° as indicated by the overlay.

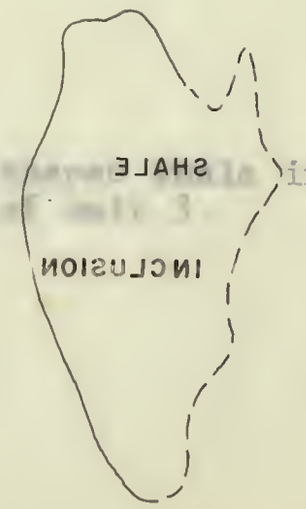
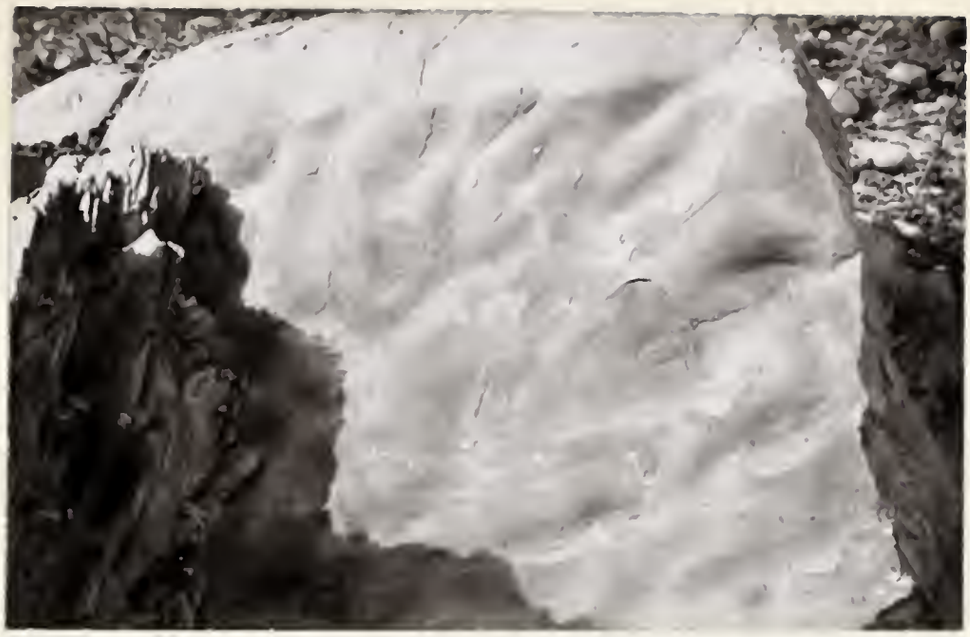


Figure 3. Irregular shale inclusion in a sandstone bed of unit 3.



Description of Plates

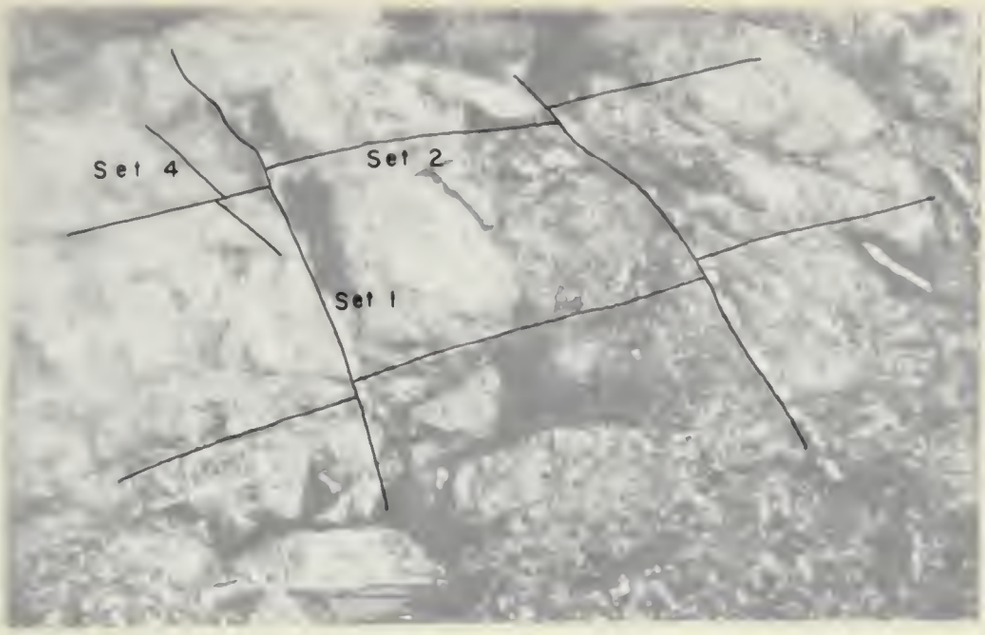
Plate 6

Field Photographs

Figure 1 Vein system on the dip slope of unit 3. Three vein sets (sets 1, 2 and 4) showing their relationship.

Figure 2 Displacement in the 3 vein sets of Fig. 1. Set 4 preceeded the other two; set 1 was formed last.

Figure 3 Vein system in the same unit as Figs. 1 and 2. No displacement occurs along these veins.


Set 4
Set 2
Set 1

Set 2
Set 4
Set 1

Set 2
Set 1

Set 2
Set 4
Set 1

Set 2
Set 4
Set 1

Set 2
Set 1

Description of Plates

Plate 7

Thin-Section Photomicrographs

Figure 1 Subarkosic conglomerate (at 140') - Small pebbles of vein quartz left and right, sand-sized grains of quartz and albite center, small amount of sericite matrix appearing as white flecks; crossed nicols, x20.

Figure 2 Feldspathic graywacke (at 126') - Sand-sized grains of quartz and some feldspar (white), magnetite (?) (black), matrix of sericite and chlorite; plane polarized light, x80.

Figure 3 Subarkose (at 436') - Mostly quartz grains, some altered feldspar, very poorly sorted, about 5% sericite and chlorite matrix; crossed nicols, x20.

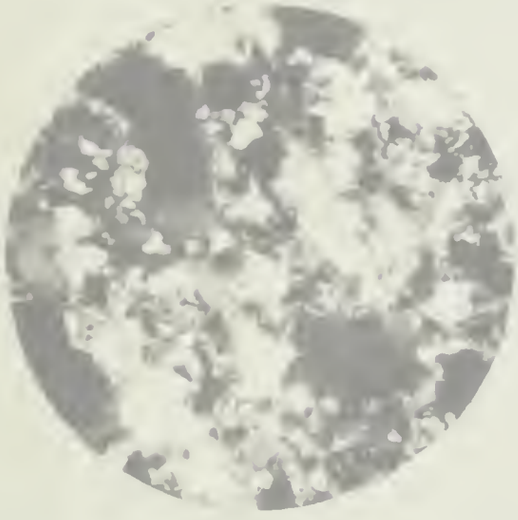
Figure 4 Arkosic conglomerate (at 300') - Large feldspar pebble center partially altered to sericite, dark grains right and left of unaltered feldspar; crossed nicols, x20.

Figure 5 Pebbly arkose (at 283') - Small albite pebble showing chess-board albite twinning; crossed nicols, x20.

Figure 6 Arkosic conglomerate (at 300') - Small albite pebble showing chess-board albite twinning; crossed nicols, x20.

1

2



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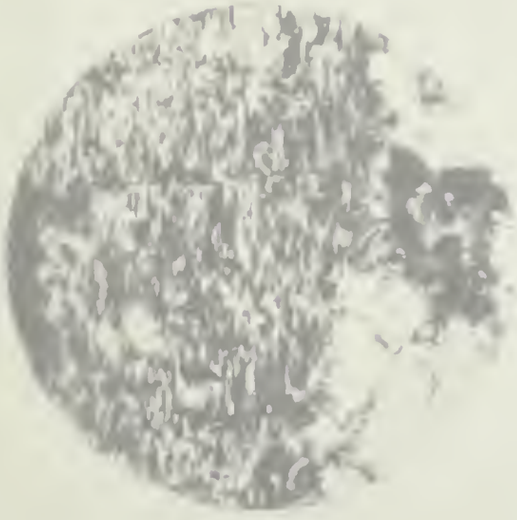


5

6

PLATE 7

Figure 1 - Tuffaceous conglomerate (at 140') - Small pebble of rock quartz left and right, sand-sized matrix of quartz and albite center, matrix of sericite matrix appearing [illegible] crossed nicols, x20.

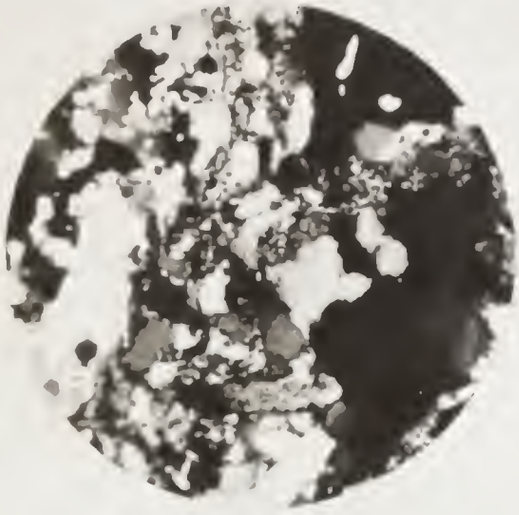
Figure 2 - Tuffaceous greywacke (at 126') - Sand-sized grains of quartz and some feldspar (white), magnetite (?) (black), matrix of sericite and chlorite; plane polarized light, x80.

Figure 3 - Greywacke (at 430') - Mostly quartz grains, some altered feldspar, very poorly sorted, matrix of sericite and chlorite material, crossed nicols, x80.

Figure 4 - Albite conglomerate (at 300') - Large feldspar pebble center partially altered to sericite, clast grains right and left of unaltered feldspar, crossed nicols, x20.

Figure 5 - Felsite breccia (at 293') - Small albite pebble showing cheese-board albite twinning; crossed nicols, x80.

Figure 6 - Albite conglomerate (at 300') - Small albite pebble showing cheese-board albite twinning; crossed nicols, x20.



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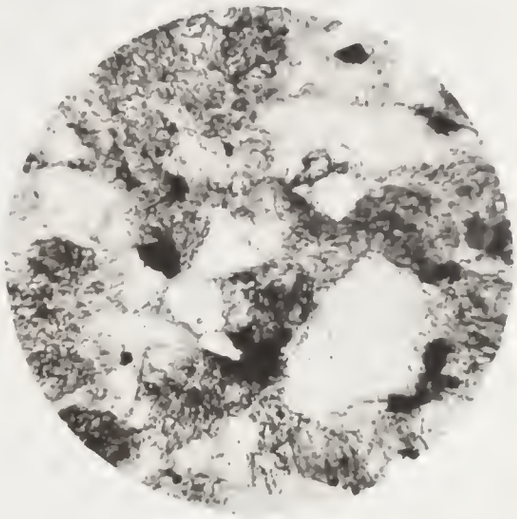

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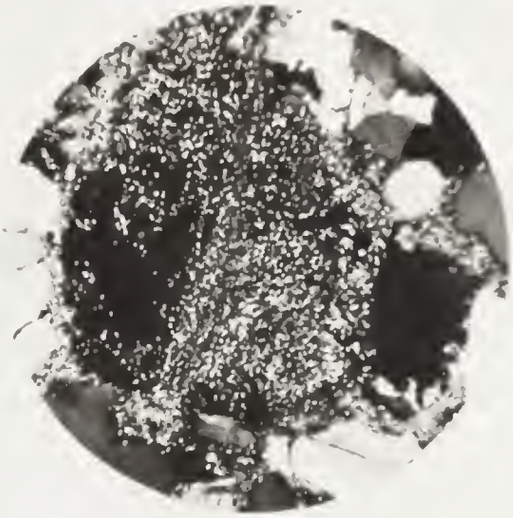

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5

6

PLATE 7

Description of Plates

Plate 8

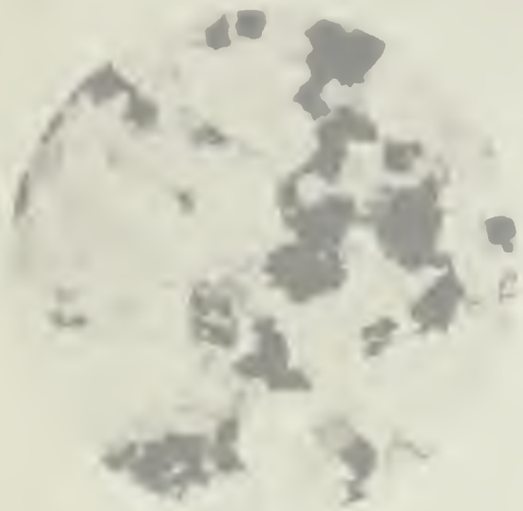
Thin-Section Photomicrographs

Figure 1 Arkose (at 51') - Siderite (ankerite ?) rhombs partially or completely altered to limonite (rhomb in lower center only partially altered), white grains are quartz and feldspar; plane polarized light, x20.

Figure 2 Subarkose (at 436') - Vermicular chlorite in feldspar and quartz grains; plane polarized light, x80.

Figure 3 Vein (2nd set) - Mostly vermicular chlorite (dark), simple twinned albite in center; crossed nicols, x20.

Figure 4 Vein (2nd set) - Chlorite showing worm-eaten pattern in the chlorite veins; plane polarized light, x20.



1

2

3

4

PLATE 8

Explanation of Plates

Plate 3

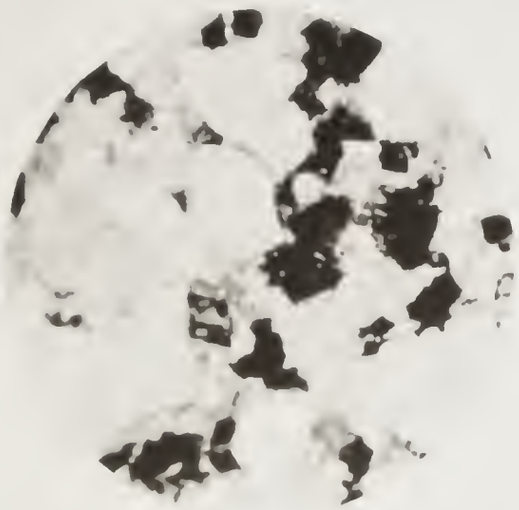
Photomicrographs

Figure 1 Ankerite (at 415') - Siderite (ankerite ?) [illegible] or completely altered to [illegible] (green in lower center only partially altered), white grains are quartz and feldspar, plane polarized light, x20.

Figure 2 Ankerite (at 436') - Vermicular chlorite in feldspar and quartz grains; plane polarized light, x80.

Figure 3 Schist (2nd sec) - Mostly vermicular chlorite (dark), locally twinned albite in center; crossed nicols, x20.

Figure 4 Vein (2nd sec) - Chlorite showing [illegible] zircons in the chlorite veins; plane polarized light, x20.



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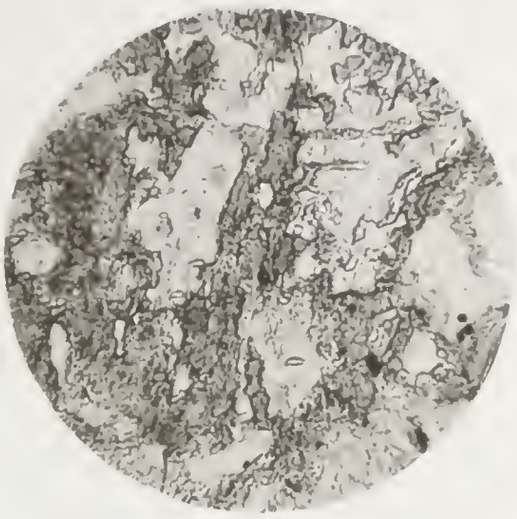

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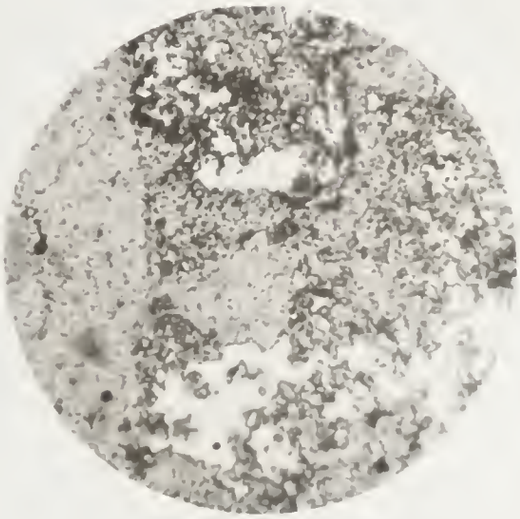

4

PLATE 8

Description of Plates

Plate 9

Photographs of Hand Samples

Figure 1 Subarkose (at 413') - Light brownish gray, very coarse-grained with a few small pebbles, mostly subangular quartz and feldspar grains, sericite matrix; reflected light, x1.5.

Figure 2 Subarkosic conglomerate (at 224') - Light olive-gray, fine pebbles of quartz and feldspar, frequent chloritized pebbles, typical conglomerate of the psammitic units; reflected light, x1.

Figure 3 Subarkosic conglomerate (at 100') - Greenish gray, large subangular pebbles of quartz and feldspar, abundant matrix of sericite and fine quartz and feldspar; reflected light, x1.

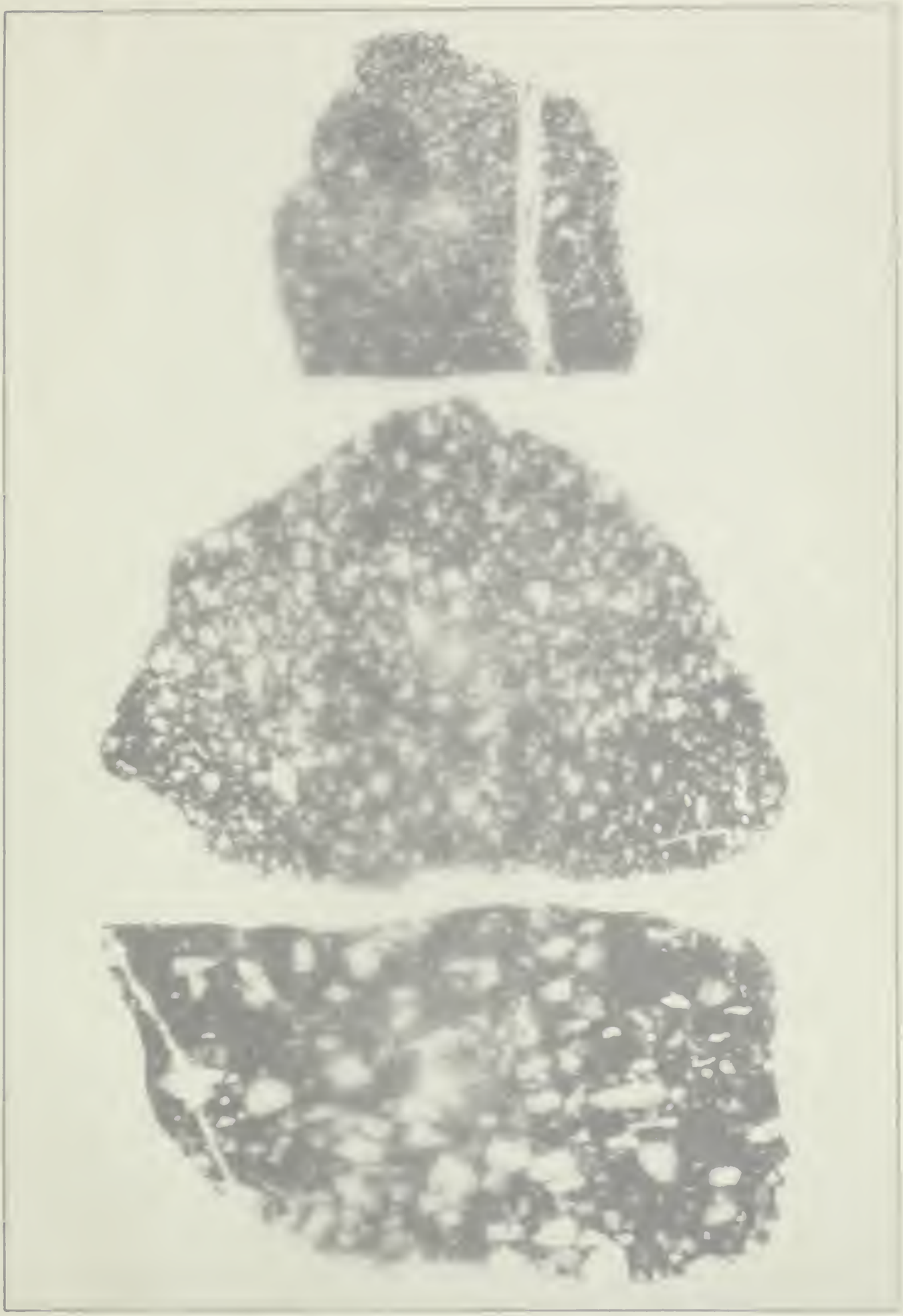

PLATE 9

Description of Plates

Plate V

Photographs of Hand Samples

Figure 1 Sandstone (at 413') - Light brownish gray, very coarse-grained with a few small pebbles, mostly subangular quartz and feldspar grains, sericitic matrix; reflected light, x1.5.

Figure 2 Subarkosic conglomerate (at 224') - Light olive-gray, fine pebbles of quartz and feldspar, frequent chloritized pebbles, typical conglomerate of the psammitic units; reflected light, x1.

Figure 3 Subgraywacke conglomerate (at 100') - Greenish gray, large subangular pebbles of quartz and feldspar, abundant matrix of sericite and fine quartz and feldspar; reflected light, x1.

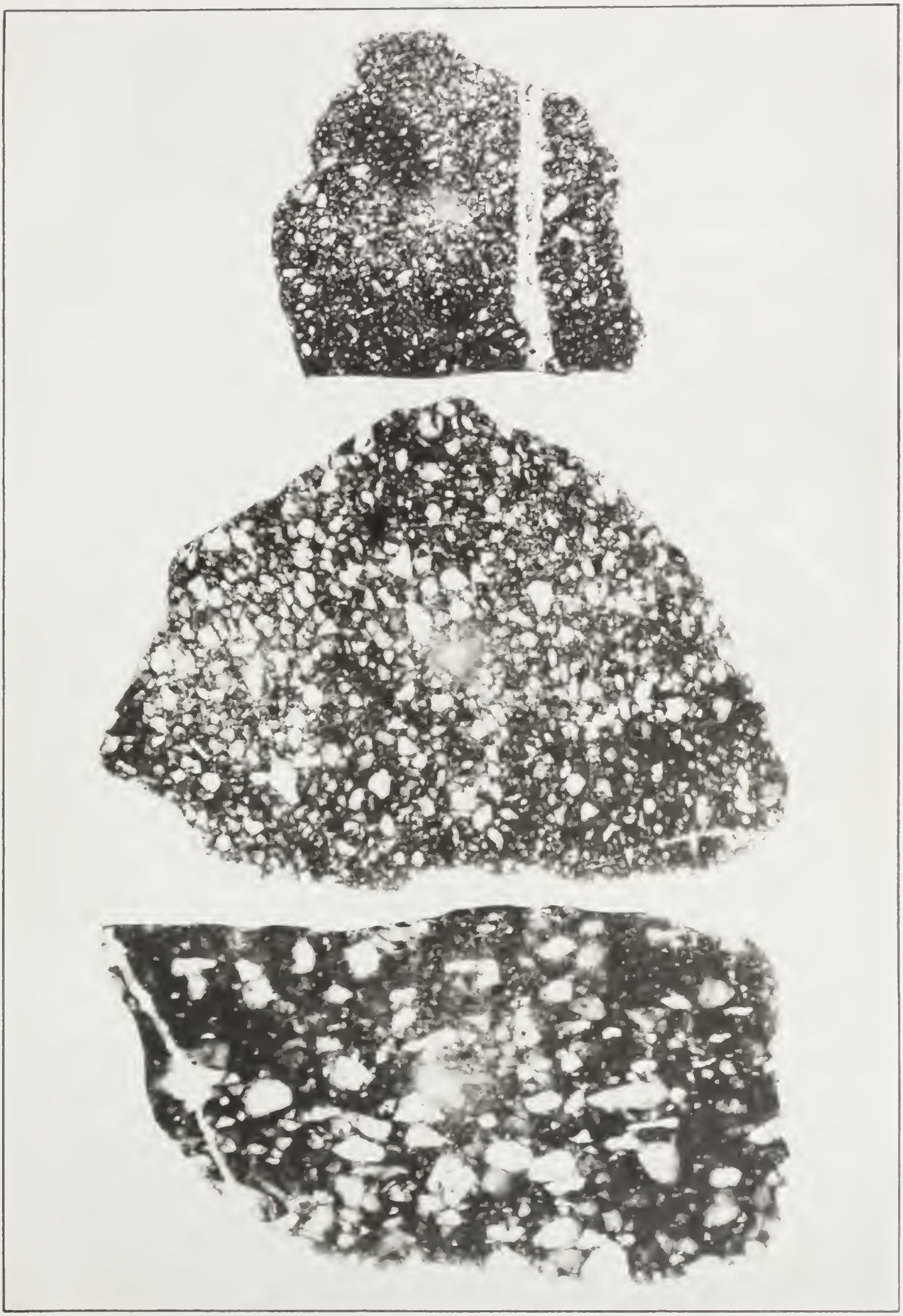

PLATE 9

Description of Plates

Plate 10

Heavy Mineral Photomicrographs

Figure 1 Apatite - Colorless, subhedral-anhedral, subangular; x320.

Figure 2 Apatite - Light brown, subhedral-anhedral, subangular, numerous small vacuoles, zoned (?); x320.

Figure 3 Tourmaline - Light olive-brown, subhedral, subangular, fractured; x320.

Figure 4 Tourmaline - Dark yellowish orange, anhedral-subhedral, angular; x320.

Figure 5 Rutile - Dark brown, subhedral, subrounded (?), oblique striations; x320.

Figure 6 Zircon - Clear pale hyacinth, subhedral, well rounded; x320.

Figure 7 Zircon - Cloudy hyacinth, subhedral, rounded, zoned; x320.

Figure 8 Zircon - Cloudy hyacinth center (zoned) with a clear hyacinth periphery, subhedral, rounded; x320.

Figure 9 Zircon - Cloudy hyacinth, euhedral, sub-rounded; x320.

Figure 10 Zircon - Dark purple-brown, subhedral, sub-rounded, malacon, slightly zoned, x320.

PLATE 10

Description of Plates

Plate 10

Heavy Mineral Photomicrographs

Figure 1 Epidote - Colorless, subhedral-anhedral, [illegible]; x320.

Figure 2 Zoisite - Light brown, subhedral-anhedral, [illegible], numerous small vacuoles, zoned [illegible] x320.

Figure 3 Tourmaline - Light olive-brown, subhedral, [illegible], fractured; x320.

Figure 4 Hornblende - Dark yellowish orange, anhedral-subhedral, angular; x320.

Figure 5 Biotite - Dark brown, subhedral, [illegible] oblique striations; x320.

Figure 6 Zircon - Clear pale hyacinth, subhedral, well rounded; x320.

Figure 7 Zircon - Cloudy hyacinth, subhedral, rounded, zoned; x320.

Figure 8 Zircon - Cloudy hyacinth center (zoned) with a clear hyacinth periphery, subhedral, rounded; x320.

Figure 9 Zircon - Cloudy hyacinth, euhedral, sub-rounded; x320.

Figure 10 Zircon - Dark purple-brown, subhedral, sub-rounded, [illegible], slightly zoned, x320.

PLATE 10

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